ISSN: 3048-989X

Innovative Agriculture

A Monthly Magazine for Agriculture and Allied Sciences

August 2025

www.innovativeagriculture.in

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

INNOVATIVE AGRICULTURE

A MONTHLY MAGAZINE

ISSN No.: 3048 – 989X
Frequency: Monthly

Month: August
Volume: 01, Issue 10

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Content

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Zebrafish Breeding: Understanding Breeding Procedures and Behavior in Danio rerio

Ritisnata Nayak[1], Md. Shadab Alam[2], Manjulesh Pai[3], Prity[1]

[1]Fish Genetics and Biotechnology Division, ICAR-CIFE, Versova, Mumbai
[2]Department of Aquaculture, College of Fisheries, OUAT, Rangeilunda, Odisha
[3]Division of Aquaculture, ICAR-CIFE, Versova, Mumbai

1. Introduction

Zebrafish (Danio rerio) has gained widespread recognition as a powerful model organism in various fields of biological research, including genetics, developmental biology, neurobiology, toxicology, and regenerative medicine. This small freshwater teleost, native to the Indian subcontinent, offers several experimental advantages such as short generation time, external fertilization, rapid embryonic development, and optical transparency during early life stages, which allow for direct observation of internal processes in real time. One of the most compelling attributes of zebrafish is its remarkable genetic similarity to humans; approximately 70% of human genes have at least one zebrafish ortholog, and 84% of genes known to be associated with human diseases have a zebrafish counterpart. These features make it particularly valuable for functional genomics, drug discovery, and modeling human diseases. Given the increasing reliance on zebrafish for high-throughput screening and translational research, the need for a consistent, high-quality, and genetically traceable breeding stock has become increasingly crucial. Variability in genetic background or health status can introduce significant experimental noise, potentially compromising research outcomes. Therefore, standardized breeding protocols, pathogen-free environments, and well-characterized genetic lines are essential for ensuring reproducibility and reliability in experimental studies. By understanding the breeding behavior, reproductive physiology, and optimal environmental conditions required for zebrafish propagation, researchers can ensure the effective maintenance of zebrafish colonies and the successful execution of experiments that rely on this dynamic model organism.

1. Centre for Zebrafish Breeding and Genetic Research (CZebraG), ICAR-CIFE

In this context, the Centre for Zebrafish Breeding and Genetic Research (CZebraG) at ICAR-Central Institute of Fisheries Education (CIFE), Mumbai, plays a pioneering role in advancing zebrafish-based research across India and globally. Established in 2019, CZebraG is India's first dedicated Danio rerio genetic resource center, offering a stable supply of pathogen-free, pedigreed, and genetically characterized zebrafish for applications in toxicology, genetics, developmental biology, and biomedical sciences (ICAR-CIFE, 2021). The facility supports over 25 national laboratories and collaborates with more than 400 global institutions, highlighting its strategic importance in the international zebrafish research ecosystem (ICAR-CIFE, 2021; Rajendran et al., 2020). CZebraG maintains zebrafish lines with inbreeding coefficients ranging from 12.5% to over 50%, enabling controlled experiments on genetic variation. Genetic fidelity is ensured through regular monitoring of inbred stocks using microsatellite markers to detect loss of heterozygosity (ICAR-CIFE, 2022). The center also plays a critical role in the development of both inbred and crossbred zebrafish stocks, estimation of genetic parameters for growth and fitness traits, and the on-demand supply of zebrafish seed to academic and institutional researchers. It routinely produces and distributes genetically traceable seed for student projects and institutional trials, thus supporting educational infrastructure and early-stage research across disciplines (Pathan et al., 2019).

Its infrastructure includes temperature-regulated, modular tanks of various capacities, and advanced filtration units that collectively support a capacity of 10,000 adult zebrafish. The facility also emphasizes standardized husbandry protocols, structured breeding schemes, and genetic documentation, as recommended for national model organism platforms (Pathan et al., 2019). This ensures reproducibility and reliability across independent experiments and contributes to reducing inter-laboratory variability. By fulfilling both research and educational needs, CZebraG has become an essential node in India's growing zebrafish research and toxicogenomics landscape.

2. Controlled Breeding and Environmental Management in Zebrafish Research Facilities

A well-structured and controlled breeding infrastructure is essential for maintaining healthy and genetically consistent zebrafish (Danio rerio) stocks, particularly in research-intensive settings like the Centre for Zebrafish Breeding and Genetic Research (CZebraG). The breeding setup typically employs specialized breeding tanks equipped with mesh or grid bottoms (using marbles, etc.) , which serve a dual purpose; facilitating the collection of fertilized eggs while preventing adult zebrafish from consuming them, a common issue observed during natural spawning events (Lawrence, 2007; Westerfield, 2000). Gentle mechanical or sponge filtration systems are used to maintain clean water without creating strong currents that might disrupt mating behavior or egg settlement (Avdesh et al., 2012). Stable water parameters are critical; the temperature is consistently regulated between 26°C and 28°C, and the pH is maintained near neutrality (6.8–7.5), closely mimicking the species' natural habitat (Kimmel et al., 1995; Lawrence, 2012). Photoperiod manipulation is also a crucial environmental control used in zebrafish breeding programs. A light cycle of 14 hours light followed by 10 hours dark simulates subtropical daylight patterns and helps synchronize circadian rhythms to induce spawning behavior early in the light phase (Nüsslein-Volhard and Dahm, 2002). Prior to mating, males and females are separated and conditioned for 7 to 10 days to maximize reproductive output. Conditioning involves feeding with protein-rich diets, including live feed such as Artemia nauplii, rotifers, or high-quality frozen alternatives, which enhances gamete viability and improves fertilization rates (Lawrence, 2012; Pathan et al., 2019). This period of dietary enrichment promotes gonadal maturation and synchronizes spawning readiness between sexes, a practice standard in most zebrafish facilities engaged in developmental biology, toxicology, and genetic studies (Parichy et al., 2009).

Such structured breeding infrastructure and standardized husbandry protocols not only ensure consistent egg production but also enhance experimental reproducibility in studies involving early developmental stages, gene expression analysis, and toxicogenomic assays. Facilities like CZebraG integrate these protocols, further enhancing water quality control and animal welfare (ICAR-CIFE, 2021). Overall, the integration of advanced environmental, nutritional, and behavioral management in zebrafish breeding setups ensures both the welfare of broodstock and the reliability of experimental outcomes.

3. Breeding Procedure and Mating Design for Genetically Controlled Zebrafish Lines

Breeding of zebrafish (Danio rerio) is typically initiated in the early hours of the day to synchronize with the species' natural circadian spawning rhythm, which is known to peak shortly after the onset of light (Nasiadka and Clark, 2012). At the Centre for Zebrafish Breeding and Genetic Research (CZebraG), the breeding process is carefully managed through standardized protocols to ensure genetic traceability and reproducibility of experimental results. Conditioned adult zebrafish males and females separately reared and nourished with high-quality live or frozen diets—are introduced into breeding tanks at a typical ratio of 1:1. This ratio enhances the likelihood of successful mating and fertilization.

The most widely adopted breeding strategy at CZebraG is single pair mating, wherein a single male is paired with a single female. This method offers advantages over group spawning by ensuring control over the genetic lineage of offspring and enabling precise tracking of parental contributions (Westerfield, 2000). Such control is critical when working with inbred or transgenic lines, where pedigree accuracy influences the validity of experimental outcomes. For example, a routine breeding session conducted on 1st–2nd July 2024 (Table 1) demonstrated variable fertilization rates across different mating pairs, underscoring the importance of individualized monitoring. In tanks C1 and C3, very low fertilization was observed (1 and 6 eggs, respectively), while tank C2 and C5 yielded 80 and 79 fertilized eggs respectively with only 28 and 4 unfertilized, indicating optimal reproductive synchronization.

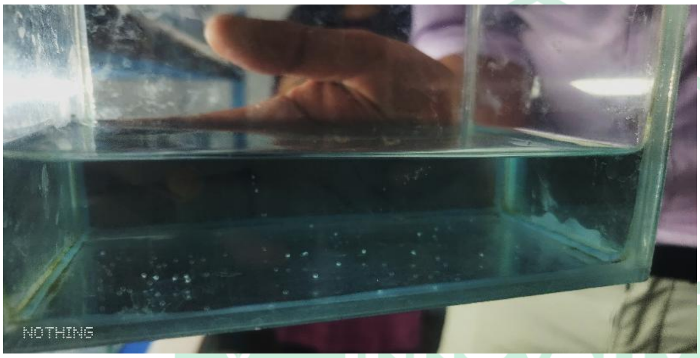
Regular documentation of breeding records, including male and female IDs, egg fertilization success, and batch details, allows for continuous improvement in stock management and selective breeding. Accurate and consistent record keeping is fundamental to effective zebrafish facility management and experimental reproducibility. Records encompass detailed logs of breeding events, stock lineage, inbreeding coefficients, feeding regimens, health observations, water quality parameters, and experimental interventions. Breeding records typically include mating dates, male and female IDs, spawning outcomes (e.g., fertilized and unfertilized egg counts), hatching rates, and developmental milestones. This enables retrospective tracking of genetic lineage and identification of reproductive performance trends. Genetic management of inbred lines also relies on pedigree tracking to monitor loss of heterozygosity and prevent unintentional genetic drift. Additionally, environmental

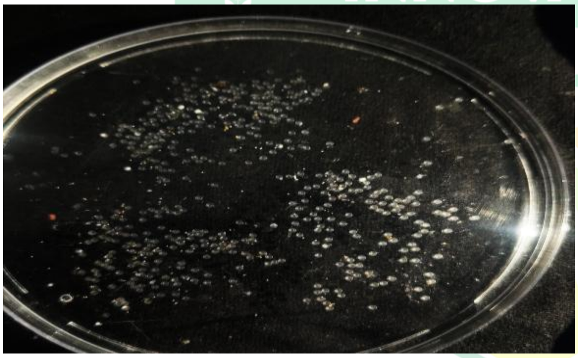
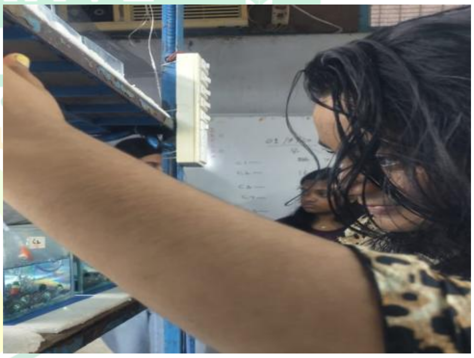
ISSN : 3048 - 989X

parameters such as temperature, pH, ammonia, nitrite, and photoperiod are recorded daily to ensure compliance with optimal husbandry standards and to detect deviations that may affect fish health or behavior (Varga, 2016). These records not only facilitate routine facility operations but are also critical for compliance with institutional animal care and use protocols, external audits, and publication requirements. With the growing complexity of zebrafish-based studies, digital management systems and barcoded tank labeling are increasingly adopted to streamline data integration and enhance traceability (Aleström et al., 2020). These practices are particularly important for inbred zebrafish lines maintained at ICAR-CIFE, where loss of heterozygosity is systematically tracked using molecular markers (Pathan et al., 2019; ICAR-CIFE, 2021).

Table 1: Sample Spawning Records (01–02 July 2024)

Tank No	Male ID	Female ID	Fertilized Eggs	Unfertilized Eggs
C1	217	216	1	157
C2	209	16	80	28
C3	251	738	6	188
C4	796	780	--	--
C5	791	97	79	4



4. Breeding Behavior of Zebrafish

Zebrafish (Danio rerio) exhibit distinct and well-characterized reproductive behaviors that are closely regulated by environmental cues, especially light. The onset of the photoperiod, particularly in the early morning, acts as a primary trigger for initiating courtship and spawning. Courtship behavior typically begins with the male actively pursuing the female, exhibiting frequent chasing and nudging of the female's abdomen using his snout. This physical stimulation helps induce ovulation and facilitates the release of mature oocytes from the female (Spence and Smith, 2006). Spawning usually occurs within the first 1–2 hours after the light cycle begins. The female releases eggs near the substrate, which are then externally fertilized by the male. This form of external fertilization is characteristic of broadcast spawners like zebrafish, where fertilization success is highly influenced by the timing, proximity, and responsiveness of both sexes (Lawrence, 2007). The eggs, being non-adhesive and denser than water, settle at the bottom of the tank and are often collected using mesh bottoms or spawning traps (marbles, in our case) to prevent predation by the adult fish.

The highly stereotyped and predictable spawning behavior of zebrafish makes them exceptionally suited for controlled breeding and experimental manipulation. Understanding the nuances of their breeding behavior, including environmental sensitivity and male–female interactions, is essential for optimizing fertility outcomes and maintaining healthy genetic lines in laboratory conditions.

5. Egg Collection and Incubation

Immediately following successful spawning, it is essential to remove the adult zebrafish from the breeding tanks to prevent egg predation, a common issue in zebrafish husbandry (Lawrence, 2007). The fertilized eggs, which are typically transparent, spherical, and 0.7–0.8 mm in diameter, either settle at the bottom or adhere to the sides and surfaces of the tank depending on flow and tank material. These eggs are gently collected using fine mesh nets or siphoning techniques and are subsequently transferred to sterile Petri dishes or incubation trays containing embryo water prepared with reverse osmosis water and buffered with salts such as NaCl, KCl, $CaCl_2$, and $MgSO_4$.

The eggs are incubated at a constant temperature of 26-28°C, which is considered optimal for zebrafish embryonic development. Under these conditions, embryogenesis progresses rapidly, and hatching generally occurs within 48-72 hours post-fertilization (Kimmel et al., 1995). During this period, embryos are observed under a stereozoommicroscope to assess fertilization success and morphological normalcy, and any unfertilized or dead embryos are removed to prevent microbial contamination. To inhibit fungal infections, especially in dense egg batches, a mild antifungal agent such as methylene blue (0.0001-0.0002%) may be added to the incubation medium. Alternatively, commercially available antifungal solutions can be used based on facility SOPs (Nasiadka and Clark, 2012). Regular water quality monitoring is crucial during this stage. Parameters such as temperature, pH (ideally 6.8–7.5), dissolved oxygen, and ammonia levels are closely maintained to ensure optimal hatching rates and embryo viability (Harper and Lawrence, 2011).

This highly standardized incubation process not only supports high survival rates but also facilitates synchronized developmental staging, which is vital for downstream applications in developmental biology, in-vitro embryo culture, toxicology, and gene expression studies.

6. Larval Rearing and Maintenance

Zebrafish larvae emerge from the chorion approximately 48-72 hours post-fertilization and become free-swimming by 3-4 days post-fertilization (dpf), at which point active exogenous feeding is required (Kimmel et al., 1995). During the initial stages, larvae rely on their yolk sac reserves, but soon transition to external feeding. At this point, they are typically offered infusoria, commercially available microdiets, or paramecia as a starter feed to support early nutritional demands and enhance survival rates. By 5-7 dpf, zebrafish larvae exhibit improved mouth gape and digestive enzyme activity, allowing gradual introduction of live feeds such as rotifers (*Brachionus plicatilis*) and freshly hatched *Artemia* nauplii. These are supplemented with finely powdered formulated diets to ensure balanced nutrition and uniform growth (Nasiadka and Clark, 2012; Phelps et al., 2020). Feed particle size and availability are crucial at this stage to prevent starvation-induced mortality and growth deformities.

Routine maintenance involves small, frequent water changes to prevent accumulation of metabolic waste, which could be toxic in early life stages. Approximately 10–30% of the rearing water is replaced daily using preconditioned water to maintain stable parameters. Ammonia levels are monitored regularly and maintained below 0.02 mg/L, with pH levels kept between 6.8 and 7.5, and temperature stabilized at 28 ± 1°C to ensure optimal metabolic activity and immune development (Harper and Lawrence, 2011). The photoperiod is maintained at 14 hours light and 10 hours dark, supporting circadian-regulated processes such as growth, feeding behavior, and hormone cycling (Del Pozo et al., 2011). This regimen also synchronizes larval development, which is particularly beneficial for experiments requiring staged embryo or larval populations.

Well-managed larval rearing practices not only enhance survivability and reduce variability in experimental populations but also serve as a foundation for maintaining high-quality zebrafish lines for downstream research.

7. Conclusion

Zebrafish breeding at the Centre for Zebrafish Breeding and Genetic Research (CZebraG), ICAR-CIFE, is conducted under meticulously controlled conditions to ensure reproducibility, genetic integrity, and high standards of animal welfare. The facility follows structured protocols for environmental control, selective mating, and genetic monitoring, which collectively contribute to the maintenance of high-quality zebrafish lines with defined genetic backgrounds. Regular monitoring and precise documentation further support the consistency and reliability of experimental outcomes. As zebrafish continue to gain prominence as a versatile model organism in diverse areas of scientific research, the breeding standards and operational practices established at ICAR-CIFE position the facility as a cornerstone of zebrafish-based research infrastructure in India and beyond.

References

Aleström, P., D'Angelo, L., Midtlyng, P.J., Schorderet, D.F., Schulte-Merker, S., Sohm, F. and Warner, S., 2020. Zebrafish: Housing and husbandry recommendations. Laboratory Animals, 54(3), pp.213–224.

Avdesh, A. et al. (2012) 'Evaluation of pharmacological models: Zebrafish', British Journal of Pharmacology, 166(6), pp. 1871–1886.

Choe, S.-K., Kim, C.-H., 2023. Zebrafish: A Powerful Model for Genetics and Genomics. Int J Mol Sci 24, 8169. https://doi.org/10.3390/ijms24098169

Del Pozo, J.L., Lam, S.H., Müller, J., Ryu, S. and Yusoff, F.M., 2011. Circadian regulation of feeding and locomotor activity in larval zebrafish (Danio rerio). Zebrafish, 8(3), pp.105–111.

Harper, C. and Lawrence, C. (2011). The Laboratory Zebrafish. CRC Press.

ICAR-CIFE (2021) *Establishment of Zebrafish Genetic Resource Centre at ICAR-CIFE*. Available at: https://krishi.icar.gov.in/jspui/handle/123456789/72571.

Kimmel, C.B., Ballard, W.W., Kimmel, S.R., Ullmann, B. and Schilling, T.F. (1995). Stages of embryonic development of the zebrafish. Developmental Dynamics, 203(3), pp.253–310.

Lawrence, C. (2007). The husbandry of zebrafish (Danio rerio): A review. Aquaculture, 269(1–4), pp.1–20.

Lawrence, C. (2012) Advances in zebrafish husbandry and management, Methods in Cell Biology, 104, pp. 429–451.

Nasiadka, A. and Clark, M.D. (2012). Zebrafish breeding in the laboratory environment. ILAR Journal, 53(2), pp.161–168.

Nüsslein-Volhard, C. and Dahm, R. (2002). Zebrafish: A Practical Approach. Oxford: Oxford University Press.

Parichy, D.M. et al. (2009) 'Normal table of postembryonic zebrafish development', Developmental Dynamics, 238(12), pp. 2975–3015.

Pathan, M.A., Chaudhari, A., Krishna, G., Madhira, S.P., 2019. Inbred zebrafish lines: A genetic repository for zebrafish researchers. IJGPB 79. https://doi.org/10.31742/IJGPB.79S.1.4

Phelps, H.A., D'Agostino, J., Harper, C., McCann, M.E. and Lawrence, C., 2020. The effects of feeding regimens on zebrafish larval survival, growth, and development. Zebrafish, 17(3), pp.207–218.

Suurväli, J., Whiteley, A.R., Zheng, Y., Gharbi, K., Leptin, M., Wiehe, T., 2019. The Laboratory Domestication of Zebrafish: From Diverse Populations to Inbred Substrains. Molecular Biology and Evolution 37, 1056. https://doi.org/10.1093/molbev/msz289

Varga, Z.M., 2016. Aquaculture, husbandry, and shipping at the Zebrafish International Resource Center. Methods in Cell Biology, 135, pp.509–534.

Westerfield, M. (2000) The Zebrafish Book: A guide for the laboratory use of zebrafish (Danio rerio). 4th edn. Eugene: University of Oregon Press.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Zebrafish as a model for Integrative Toxicogenomics: CRISPR Editing, Phenotyping, and Molecular Insights

Ritisnata Nayak[1], Md. Shadab Alam[2], Manjulesh Pai[3], Prity[1]

[1]Fish Genetics and Biotechnology Division, ICAR-CIFE, Versova, Mumbai
[2]Department of Aquaculture, College of Fisheries, OUAT, Rangeilunda, Odisha
[3]Division of Aquaculture, ICAR-CIFE, Versova, Mumbai

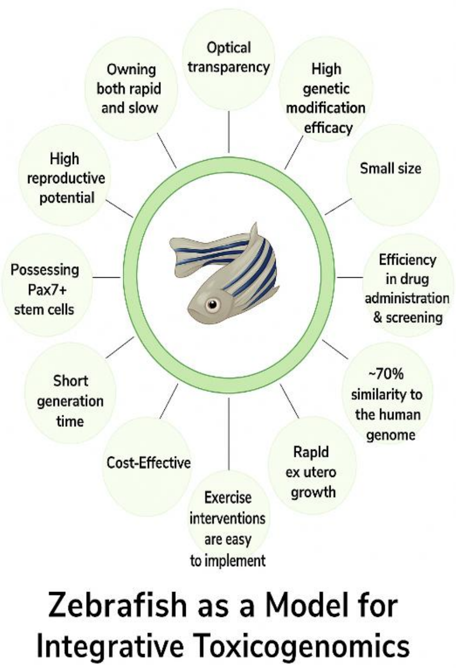
1. Introduction

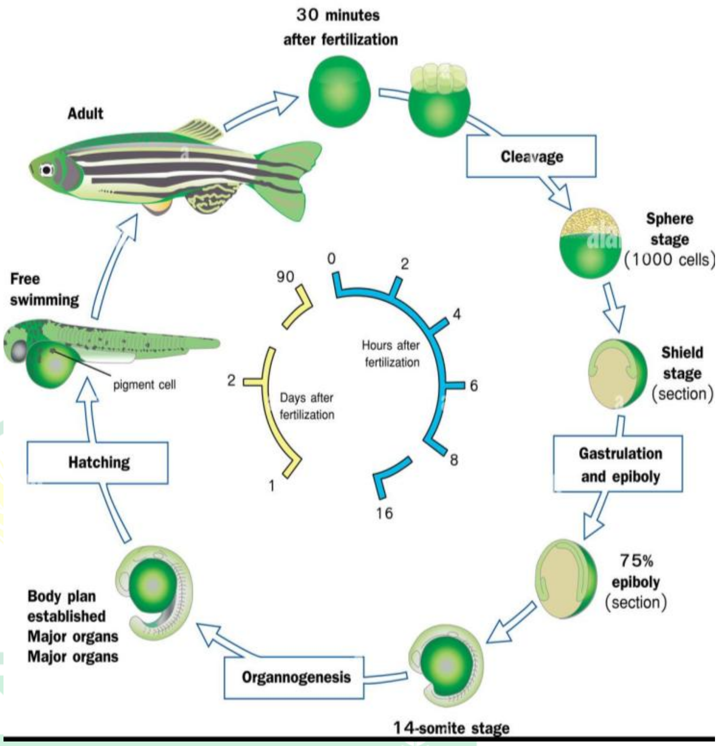
In the ever-evolving fields of biomedical and environmental research, scientists are constantly seeking model organisms that can provide deep insights into human health, disease, and the biological consequences of exposure to environmental pollutants. Surprisingly, one of the most powerful models in this quest is not a mammal or a primate, but a small freshwater fish; the zebrafish. Measuring only a few centimeters in length, *Danio rerio* may appear unremarkable at first glance. However, this tiny, striped fish has made a significant impact on modern science and is now recognized globally as a versatile and reliable model organism. Zebrafish (*Danio rerio*) have emerged as a powerful vertebrate model organism in the fields of biomedical research, developmental biology, and, more recently, integrative toxicogenomics. Despite their small size and relatively simple appearance, zebrafish offer numerous experimental advantages that make them ideally suited for toxicological assessments and gene-environment interaction studies. In recent years, zebrafish have gained prominence in the emerging field of toxicogenomics; the intersection of toxicology and genomics, which seeks to understand how genes respond to potentially harmful substances at the molecular level.

2. Why Zebrafish?

What makes the zebrafish truly exceptional is a unique combination of biological features that are rarely found together in other models. Zebrafish embryos are optically transparent, allowing researchers to observe morphological, physiological, and behavioral changes across various life stages during developmental processes in real-time without the need for invasive procedures (Kimmel et al., 1995). They develop rapidly, with major organ systems forming within just 24 to 48 hours post-fertilization. This quick developmental timeline accelerates experimental workflows and allows for the detection of effects from genetic modifications or toxic exposures in a matter of days. Even more remarkable is the genetic similarity between zebrafish and humans. Zebrafish exhibit a high degree of genetic conservation with humans, with approximately 70% of human protein-coding genes having at least one orthologue in the zebrafish genome (Howe et al., 2013). This homology makes them highly relevant for translational research, particularly in identifying conserved molecular pathways affected by environmental toxicants or pharmaceutical compounds. This makes them an excellent proxy for studying how our own bodies might react to these specific chemicals, pharmaceuticals, or environmental pollutants. Furthermore, their high fecundity, small size, and ease of maintenance facilitate large-scale high-throughput screening in both developmental and behavioral toxicology (MacRae & Peterson, 2015).

In this context, zebrafish are not just swimming in aquaria; they are revolutionizing the way we investigate the genetic and physiological responses to toxins, from heavy metals and endocrine disruptors to complex mixtures found in polluted ecosystems. They serve as living biosensors, capable of revealing subtle changes in gene expression, tissue morphology, and organ development following exposure to environmental stressors. Their use has also expanded into drug discovery, neurobiology, cancer research, and regenerative medicine.





3. CRISPR: A Precise Genetic Scalpel

The integration of CRISPR-Cas9 gene-editing technology into zebrafish research has revolutionized functional genomics and toxicological studies by enabling precise, targeted modification of specific genes. CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) functions as a molecular scalpel, allowing researchers to introduce insertions, deletions, or even specific point mutations at predetermined genomic loci with high efficiency and specificity (Hwang et al., 2013; Jao et al., 2013). In zebrafish, the CRISPR-Cas9 system has been widely adopted for generating gene knockouts to study gene function, developmental regulation, and molecular pathways implicated in toxicological responses.

In toxicogenomic applications, CRISPR-mediated gene knockouts in zebrafish are particularly useful for evaluating the role of individual genes in mediating susceptibility or resistance to chemical stressors. For example, disruption of genes encoding antioxidant enzymes such as superoxide dismutase (sod1), catalase (cat), or glutathione peroxidase (gpx1a) has been employed to investigate their roles in protecting developing embryos from oxidative damage induced by environmental toxicants (Shi et al., 2019; Yang et al., 2020). Similarly, CRISPR-mediated loss-of-function models targeting DNA repair genes such as xpc, xpd, or p53 have been instrumental in elucidating how defects in genomic maintenance pathways contribute to increased vulnerability to genotoxic agents like polycyclic aromatic hydrocarbons or microplastics (Kettleborough et al., 2013; Wang et al., 2020).

These targeted mutants, when exposed to known or suspected environmental pollutants, allow researchers to link specific phenotypic abnormalities, such as developmental deformities, cardiac dysfunction, or behavioral impairments to underlying gene-environment interactions. Moreover, CRISPR-based models facilitate high-throughput screening of chemical libraries, where phenotypic endpoints can be rapidly assessed in genetically modified embryos, accelerating the identification of both toxicants and potential protective compounds (Wu et al., 2018). As such, the application of CRISPR-Cas9 in zebrafish serves as a powerful strategy for dissecting molecular mechanisms of toxicity, validating gene function, and enhancing predictive toxicology frameworks.

4. Phenotyping: Watching Changes as They Happen

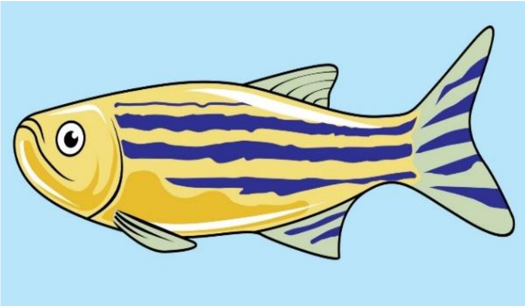
Phenotyping in zebrafish toxicology serves as a real-time, non-invasive approach to link genotypic changes or environmental exposures to observable morphological, physiological, and behavioral outcomes. Due to their optical transparency during early developmental stages and external fertilization, zebrafish embryos allow for continuous monitoring of organogenesis, circulation, pigmentation, and neurodevelopment with minimal disruption (Kalueff et al., 2013). Researchers can rapidly detect malformations in vital structures such as the brain, heart, spine, or somites, which often serve as early biomarkers of teratogenicity and developmental toxicity (Kimmel et al., 1995; Truong et al., 2014).

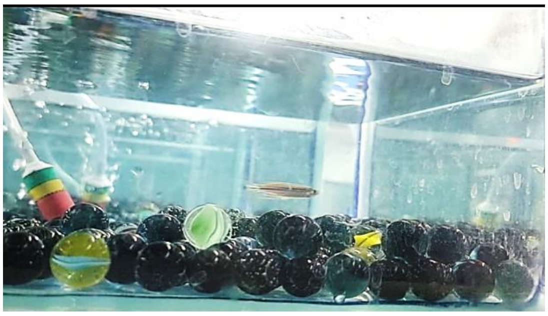
Moreover, zebrafish larvae exhibit a wide range of quantifiable behaviors including spontaneous tail coiling, touch response, swimming patterns, escape reflexes, and feeding efficiency that are highly sensitive to neurotoxic or endocrine-disrupting compounds (MacPhail et al., 2009; Stewart et al., 2012). For instance, abnormal thigmotaxis (preference for the edge of a well), hypoactivity, or impaired habituation responses can serve as indicators of disrupted neurological function or altered stress axis regulation (Levin et al., 2003; Colwill & Creton, 2011). These phenotypic endpoints are particularly valuable because they manifest rapidly, often within hours or days and precede more complex pathologies that may take weeks or months to develop in higher vertebrates.

High-content imaging and automated tracking systems have further enhanced the resolution and throughput of phenotypic screening, enabling researchers to statistically analyze changes across large sample sizes and treatment groups (Pardo-Martin et al., 2010). Collectively, these phenotypic analyses help prioritize chemicals for further molecular analysis and risk assessment, offering a reliable, cost-effective, and ethically favorable alternative to mammalian models.


5. Molecular Insights: A Window Into Gene Expression

The emergence of CRISPR/Cas9 genome editing technology has significantly enhanced the zebrafish model's utility in toxicogenomic studies. CRISPR enables precise and efficient gene knockout or knock-in, allowing researchers to investigate the function of specific genes in modulating toxic responses or disease pathogenesis (Hwang et al., 2013). When combined with transcriptomic tools, such as RNA sequencing or quantitative PCR, CRISPR-edited zebrafish lines can provide mechanistic insights into the molecular basis of toxicity, including altered gene expression, oxidative stress pathways, apoptosis, and DNA damage responses (Daniel et al., 2023). Moreover, the ability to correlate these molecular changes with phenotypic outcomes such as organ malformations, behavioral deficits, or mortality makes zebrafish a comprehensive system for integrative toxicogenomics (Santana et al., 2020). Thus, zebrafish offer a robust in vivo platform that bridges molecular, cellular, and organismal levels of toxicity evaluation, positioning them at the forefront of modern environmental and biomedical research.





While phenotypic and developmental endpoints provide essential data on toxicity, zebrafish also serve as a powerful in vivo model for understanding the molecular mechanisms underlying chemical-induced responses. At the molecular level, technologies such as quantitative PCR (qPCR), RNA sequencing (RNA-Seq), and full-transcriptome microarrays enable researchers to quantify and profile global gene expression changes in response to a wide range of toxicants, including heavy metals, pharmaceuticals, endocrine disruptors, microplastics, and herbal formulations (Marques et al., 2009; Tian et al., 2021). These tools allow for the detection of subtle but significant alterations in gene expression patterns, even at non-lethal exposure levels, offering early biomarkers of effect.

Differential gene expression analysis in zebrafish can reveal upregulation or downregulation of genes involved in critical biological pathways such as oxidative stress (e.g., sod1, cat, gpx1a), DNA damage and repair (e.g., xpd, p53), apoptosis (e.g., bax, caspase-3), inflammation (e.g., il1b, tnfa), and detoxification (e.g., cyp1a, gstp1) (Yang et al., 2020; Wang et al., 2019). These molecular signatures are often tissue-specific and can be temporally mapped to different stages of development or exposure duration. For instance, exposure to oxidative agents such as bisphenol A, heavy metals like cadmium, or microplastic fibers has been shown to cause significant perturbations in antioxidant gene regulation and pro-inflammatory cytokine expression in zebrafish larvae and adult tissues (Qiang & Cheng, 2021; Capó et al., 2021).

Transcriptomic profiling can also uncover novel or unexpected gene networks affected by toxicants, offering mechanistic insights into pathways associated with carcinogenesis, neurodevelopmental disorders, reproductive impairment, and immune dysregulation. In toxicogenomic screening studies, zebrafish embryos are often used in high-throughput platforms to assess concentration-dependent gene expression responses, enabling the derivation of benchmark doses or lowest observed effect concentrations (LOECs) at the molecular level (Santos et al., 2017).

In sum, zebrafish-based molecular assays serve as a vital component of integrative toxicogenomics by linking observable phenotypic effects with gene-level perturbations. This systems-level approach enhances the sensitivity, resolution, and translational relevance of toxicity assessments, making zebrafish a preferred vertebrate model in molecular ecotoxicology and biomedical risk evaluation.

6. A Tool for the Future

Positioned at the convergence of genetics, molecular biology, and toxicology, zebrafish (*Danio rerio*) have become an indispensable model in modern biomedical and environmental sciences. Their small size, rapid development, genetic tractability, and transparency make them exceptionally well-suited for high-throughput screening, mechanistic toxicology, and disease modeling (MacRae & Peterson, 2015; Lieschke & Currie, 2007). Moreover, the relatively low cost of maintenance and scalability of embryo-based assays render zebrafish a practical and ethically favorable alternative to traditional mammalian systems, particularly in early-stage chemical safety evaluations and functional genomics (Selderslaghs et al., 2012).As scientific priorities shift toward integrative, multi-dimensional approaches, zebrafish offer a powerful platform for toxicogenomic research, combining phenotypic screening with transcriptomic and genetic analysis to provide a comprehensive view of biological responses to environmental and pharmaceutical agents (Tanguay et al., 2014). The introduction of CRISPR/Cas9 gene-editing technology has further expanded the zebrafish model's capabilities by enabling precise manipulation of target genes to evaluate their function in toxicity pathways, disease progression, or developmental processes (Varshney et al., 2015).

Zebrafish are now routinely employed to study a wide spectrum of toxicants, from microplastics and endocrine-disrupting chemicals to nanoparticle-based formulations and herbal compounds; with endpoints ranging from behavioral anomalies and teratogenic malformations to gene expression changes and epigenetic effects (Qiang & Cheng, 2021; Zhang et al., 2022). This integrative framework makes zebrafish not merely a supplementary model, but a central tool in predictive toxicology, environmental health risk assessment, and translational biomedical research. In this context, zebrafish are not simply organisms confined to laboratory aquaria, they are active contributors to the future of science. By enabling rapid, reproducible, and mechanistic insights into toxic responses, gene functions, and developmental biology, zebrafish are helping researchers unlock the complexities of human health and environmental safety. Their role is increasingly pivotal in advancing the goals of safer chemical design, precision medicine, and sustainable environmental stewardship.

As we face global challenges related to environmental contamination, chemical safety, and the rising burden of chronic diseases, the zebrafish model offers a timely, ethical, and scientifically robust system for research that bridges basic biology and real-world applications. From laboratories to regulatory agencies, the humble zebrafish continues to make waves in science, quietly but powerfully illuminating the path toward a healthier and more sustainable future. A Tool for the Future At the intersection of genetics, molecular biology, and toxicology, zebrafish provide a fast, cost-effective, and ethically scalable platform for research. Whether used to test new drugs, evaluate environmental contaminants, or understand disease mechanisms, this small fish is opening big doors. With integrative toxicogenomics powered by CRISPR and phenotyping, zebrafish are not just swimming in tanks, they're swimming at the forefront of scientific discovery.

References

Albadri, S., Del Bene, F., Revenu, C., 2017. Genome editing using CRISPR/Cas9-based knock-in approaches in zebrafish. Methods 121–122, 77–85. https://doi.org/10.1016/j.ymeth.2017.03.005

Capó, X., Martorell-Ribera, J., Riera-Heredia, N., Rodríguez-Barreto, D., Sureda, A., & Mancera, J. M. (2021). Gene expression alterations in zebrafish (Danio rerio) exposed to environmentally relevant concentrations of polyethylene microplastics. Environmental Pollution, 268, 115684. https://doi.org/10.1016/j.envpol.2020.115684

Colwill, R. M., & Creton, R. (2011). Locomotor behaviors in zebrafish (Danio rerio) larvae. Behavioural Processes, 86(2), 222–229. https://doi.org/10.1016/j.beproc.2010.12.003

Daniel, J.G., Yu, X., Ferguson, A.C., Shavit, J.A., 2023. CRISPR/Cas9-Mediated Genome Editing in Zebrafish, in: Saunders, T.L. (Ed.), Transgenesis, Methods in Molecular Biology. Springer US, New York, NY, pp. 371–380. https://doi.org/10.1007/978-1-0716-2990-1_17

Howe, K., Clark, M. D., Torroja, C. F., Torrance, J., Berthelot, C., Muffato, M., … & Stemple, D. L. (2013). The zebrafish reference genome sequence and its relationship to the human genome. Nature, 496(7446), 498–503. https://doi.org/10.1038/nature12111

Hu, P., Zhao, X., Zhang, Q., Li, W., Zu, Y., 2018. Comparison of Various Nuclear Localization Signal-Fused Cas9 Proteins and *Cas9* mRNA for Genome Editing in Zebrafish. G3 Genes|Genomes|Genetics 8, 823–831. https://doi.org/10.1534/g3.117.300359

Hwang, W. Y., Fu, Y., Reyon, D., Maeder, M. L., Tsai, S. Q., Sander, J. D., ... & Joung, J. K. (2013). *Efficient genome editing in zebrafish using a CRISPR-Cas system.* Nature Biotechnology, 31(3), 227–229. https://doi.org/10.1038/nbt.250

Jao, L. E., Wente, S. R., & Chen, W. (2013). *Efficient multiplex biallelic zebrafish genome editing using a CRISPR nuclease system.* Proceedings of the National Academy of Sciences, 110(34), 13904–13909. https://doi.org/10.1073/pnas.1308335110

Kalueff, A. V., Stewart, A. M., & Gerlai, R. (2014). Zebrafish as an emerging model for studying complex brain disorders. Trends in Pharmacological Sciences, 35(2), 63–75. https://doi.org/10.1016/j.tips.2013.12.002

Kettleborough, R. N., Busch-Nentwich, E. M., Harvey, S. A., Dooley, C. M., de Bruijn, E., van Eeden, F., ... & Stemple, D. L. (2013). *A systematic genome-wide analysis of zebrafish protein-coding gene function.* Nature, 496(7446), 494–497. https://doi.org/10.1038/nature11992

Kimmel, C. B., Ballard, W. W., Kimmel, S. R., Ullmann, B., & Schilling, T. F. (1995). Stages of embryonic development of the zebrafish. Developmental Dynamics, 203(3), 253–310. https://doi.org/10.1002/aja.1002030302

Levin, E. D., Chrysanthis, E., Yacisin, K., & Linney, E. (2003). Prenatal nicotine exposure and cognition in zebrafish. Neurotoxicology and Teratology, 25(6), 661–668. https://doi.org/10.1016/j.ntt.2003.07.002

MacPhail, R. C., Brooks, J., Hunter, D. L., Padnos, B., Irons, T. D., & Padilla, S. (2009). Locomotion in larval zebrafish: Influence of time of day, lighting and ethanol. Neurotoxicology, 30(1), 52–58. https://doi.org/10.1016/j.neuro.2008.09.011

MacRae, C. A., & Peterson, R. T. (2015). Zebrafish as tools for drug discovery. Nature Reviews Drug Discovery, 14(10), 721–731. https://doi.org/10.1038/nrd4627

Marques, I. J., Leito, J. T. D., Spaink, H. P., Testerink, J., Jansen, H. J., Gilde, J., … & van den Berg, J. (2009). Transcriptome analysis of the response to perfluorooctanoic acid (PFOA) in zebrafish embryos. Environmental Science & Technology, 43(20), 8029–8035. https://doi.org/10.1021/es901625y

Pardo-Martin, C., Chang, T. Y., Koo, B. K., Gilleland, C. L., Wasserman, S. C., & Yanik, M. F. (2010). High-throughput in vivo vertebrate screening. Nature Methods, 7(8), 634–636. https://doi.org/10.1038/nmeth.148

Qiang, L., & Cheng, J. (2021). Microplastic exposure disturbs antioxidant and immune gene expression in adult zebrafish tissues. Chemosphere, 263, 128161. https://doi.org/10.1016/j.chemosphere.2020.128161

Santana, S., Rocco, M., Barbosa, F. Jr., & Antunes, L. M. G. (2020). Zebrafish as a model for evaluating environmental and human health toxicants. Pharmacology & Therapeutics, 212, 107556. https://doi.org/10.1016/j.pharmthera.2020.107556

Santos, D., Luzio, A., & Coimbra, A. M. (2017). High-throughput gene expression screening in zebrafish embryos exposed to neurotoxicants: A proof of concept. Ecotoxicology and Environmental Safety, 144, 78–86. https://doi.org/10.1016/j.ecoenv.2017.06.019

Shi, X., Zhang, C., Liu, Y., Xu, T., Guo, X., & Wang, Y. (2019). *Knockout of sod1 gene in zebrafish leads to developmental defects and motor neuron degeneration.* Journal of Neurochemistry, 149(2), 264–276. https://doi.org/10.1111/jnc.14683

Stewart, A. M., Nguyen, M., Wong, K., Poudel, M. K., & Kalueff, A. V. (2012). Developing zebrafish models of autism spectrum disorder (ASD). Progress in Neuro-Psychopharmacology and Biological Psychiatry, 35(6), 1400–1408. https://doi.org/10.1016/j.pnpbp.2011.05.013

Tian, L., Liu, H., Yang, C., Wu, Y., Tang, J., & Wang, Q. (2021). Transcriptomic profiling reveals oxidative stress and immune disruption in zebrafish embryos exposed to triclosan. Science of the Total Environment, 783, 146892. https://doi.org/10.1016/j.scitotenv.2021.146892

Truong, L., Reif, D. M., St Mary, L., Geier, M. C., Truong, H. D., & Tanguay, R. L. (2014). Multidimensional in vivo hazard assessment using zebrafish. Toxicological Sciences, 137(1), 212–233. https://doi.org/10.1093/toxsci/kft235

Wu, R. S., Lam, S. H., & Sze-To, W. H. (2018). *Rapid toxicity assessment using zebrafish embryos and CRISPR-generated knockout models.* Environmental Science & Technology, 52(18), 10533–10545. https://doi.org/10.1021/acs.est.8b02258

Yang, J., Wang, Y., Li, Z., Wang, D., Zhang, Y., & Hao, C. (2020). *CRISPR/Cas9-based knockout of catalase confirms its critical role in oxidative stress regulation and embryo development in zebrafish.* Aquatic Toxicology, 228, 105632. https://doi.org/10.1016/j.aquatox.2020.105632

Zhao, Y., Rahmy, S., Liu, Z., Zhang, C., Lu, X., 2020. Rational targeting of immunosuppressive neutrophils in cancer. Pharmacology & Therapeutics 212, 107556. https://doi.org/10.1016/j.pharmthera.2020.107556

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Conservation Agriculture as a Strategy for Enhancing Soil Health and Sustainability

[1]Samridhya Mukherjee, [2]Santosh Kumar Meena, [3]Anant Vyas

[1]M.Sc. Scholar, Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi
[2]M.Sc. Scholar, Department of Plant Physiology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi
[3]M.Sc. Scholar, Department of Plant Physiology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi

Abstract

Conservation Agriculture (CA) is a climate-smart, sustainable farming approach that seeks to harmonize productivity with environmental stewardship. Based on the core principles of minimum soil disturbance, permanent soil cover, and diversified crop rotations, CA offers a holistic strategy for improving soil health, enhancing water use efficiency, conserving biodiversity, and ensuring long-term agricultural sustainability. In the face of increasing soil degradation, declining fertility, and climatic variability, CA presents a promising pathway to achieve sustainable development goals (SDGs) while ensuring food security. This paper explores in depth the scientific foundations, benefits, and real-world applications of Conservation Agriculture, highlighting its role in enhancing soil physical, chemical, and biological properties. The paper also addresses the socio-economic and institutional challenges that hinder widespread adoption and proposes strategic interventions for large-scale implementation.

Keywords: Conservation Agriculture, Soil Health, No-till Farming, Crop Diversification, Sustainable Agriculture, Soil Organic Carbon, Water Use Efficiency, Resilient Farming Systems

1. Introduction

Agricultural sustainability is under severe pressure due to rapid population growth, land degradation, water scarcity, and climate change. Soil—the foundation of terrestrial ecosystems and food production—faces widespread degradation through erosion, nutrient depletion, compaction, loss of organic matter, and reduced biological activity. The consequences are alarming: lower yields, increased production costs, loss of biodiversity, and vulnerability to climatic stresses.

Conventional farming systems, characterized by intensive tillage, monocropping, excessive use of agrochemicals, and poor residue management, have exacerbated these problems. In contrast, **Conservation Agriculture (CA)** offers a paradigm shift that seeks to regenerate soil, restore ecological balance, and increase farm resilience through nature-aligned practices.

This paper aims to explore how CA enhances soil health and contributes to sustainability. It delves into the scientific mechanisms, reviews global experiences, examines challenges to adoption, and proposes policy and research directions.

2. Principles of Conservation Agriculture

2.1 Principle 1: Minimal Soil Disturbance

Tillage disrupts natural soil structure, destroys macro-aggregates, accelerates organic matter loss, and disturbs soil biota. CA promotes zero or reduced tillage, allowing biological processes like root penetration, earthworm activity, and microbial colonization to maintain soil structure and function. Over time, this leads to:

1) Enhanced aggregate stability
2) Improved soil porosity and aeration
3) Reduced risk of erosion and crusting
4) Energy and labor savings due to fewer field operations

2.2 Principle 2: Permanent Soil Organic Cover

Maintaining soil cover using crop residues or live cover crops plays a crucial role in moderating soil temperature, retaining moisture, suppressing weeds, and preventing erosion. Mulching also supports microbial habitats and nutrient recycling. Benefits include:

1) Reduced surface runoff and evaporation
2) Better infiltration and water retention
3) Enhanced carbon input to the soil
4) Suppressed weed growth and improved soil fauna activity

2.3 Principle 3: Crop Rotation and Diversification

Growing diverse crops in sequence or simultaneously (e.g., intercropping, relay cropping) improves nutrient use efficiency, reduces pest/disease cycles, and enhances biodiversity. Inclusion of legumes, deep-rooted species, and cover crops increases biological nitrogen fixation and improves subsoil health.

3. Soil Health Enhancement through Conservation Agriculture

3.1 Physical Health

CA improves physical soil properties over time:

1) **Aggregate Stability**: No-till practices allow formation of macroaggregates bound by microbial secretions and organic matter.
2) **Bulk Density and Porosity**: Reduced tillage maintains pore space, facilitating air and water movement.
3) **Infiltration Rate**: Mulch and improved structure enhance rainwater absorption, reducing waterlogging and erosion.

3.2 Chemical Health

1) **Organic Carbon**: CA helps accumulate Soil Organic Carbon (SOC) through residue retention and minimized oxidation. SOC enhances nutrient availability and cation exchange capacity.
2) **Soil pH**: CA systems maintain a more balanced pH due to minimal disruption and organic acid production from residues.
3) **Nutrient Stratification**: Though stratification can occur under no-till, targeted nutrient placement and deep-rooted cover crops can address it.

3.3 Biological Health

1) **Microbial Diversity**: CA increases abundance and diversity of soil bacteria, fungi (especially arbuscular mycorrhizal fungi), and actinomycetes.
2) **Enzyme Activities**: Enzymes like dehydrogenase, phosphatase, and β-glucosidase are more active in CA systems, indicating enhanced nutrient cycling.
3) **Macrofauna**: Earthworms, nematodes, and arthropods thrive under residue cover, aiding decomposition and soil mixing.

4. Long-Term Environmental Benefits of Conservation Agriculture

4.1 Soil Erosion Control

By protecting the soil surface with mulch and minimizing tillage, CA drastically reduces both wind and water erosion. Studies report reductions of 50–90% in erosion losses compared to conventional tillage systems.

4.2 Carbon Sequestration and Climate Change Mitigation

CA supports carbon sequestration by reducing oxidation of organic matter and facilitating continuous organic inputs. Long-term CA fields can sequester 0.1–0.5 t C ha^{-1} $year^{-1}$. Additionally, reduced tillage lowers fuel consumption and greenhouse gas emissions.

4.3 Improved Water Use Efficiency

Residue cover and improved structure increase soil water holding capacity and reduce evaporation. CA is particularly effective in semi-arid regions where water is a limiting factor.

4.4 Biodiversity Conservation

CA provides habitats for a variety of organisms, both above and below ground. Pollinators, natural enemies, and beneficial insects find shelter in diversified cropping systems with cover.

4.5 Reduced Input Dependency

Over time, CA systems require fewer synthetic inputs due to improved nutrient recycling, pest suppression, and soil resilience. This translates into lower costs and reduced environmental impact.

5. Conservation Agriculture and Sustainable Development

CA directly contributes to achieving the following **Sustainable Development Goals (SDGs)**:

SDG	Contribution through CA
SDG 2	Sustainable food production and improved nutrition
SDG 6	Enhanced water-use efficiency and quality
SDG 13	Climate change mitigation via carbon sequestration
SDG 15	Restoration of degraded land and biodiversity conservation

6. Global Perspectives and Case Studies

6.1 South Asia (India, Pakistan, Bangladesh)

In the **Indo-Gangetic Plains**, CA practices like zero-till wheat, direct-seeded rice (DSR), and crop residue management have reduced production costs and improved soil fertility. Use of **Happy Seeder** technology prevents residue burning and retains mulch on the soil.

6.2 Latin America (Brazil, Argentina, Paraguay)

Latin America is a global leader in CA. Brazil has over 30 million hectares under CA. Adoption of no-till soybeans, maize, and wheat with effective rotation has reversed severe erosion and built resilient soils.

6.3 Sub-Saharan Africa

Despite challenges, CA is gaining traction in Malawi, Zambia, and Kenya through donor-funded initiatives. Intercropping maize with legumes (e.g., pigeon pea) and mulching improves soil health and food security.

6.4 North America

In the U.S., large-scale CA adoption is driven by precision technologies, cover cropping, and carbon markets. USDA programs support farmers in implementing CA as part of conservation stewardship plans.

7. Integration of CA with Other Sustainable Practices

7.1 Conservation Agriculture and Agroforestry

Combining trees with CA practices improves microclimate, diversifies income, and stabilizes soil. Agroforestry buffers extreme weather impacts and supports pollinator habitats.

7.2 CA and Integrated Nutrient Management (INM)

Combining organic inputs (compost, biofertilizers) with minimal synthetic fertilizers enhances nutrient efficiency and reduces environmental footprint.

7.3 CA and Precision Agriculture

Sensor-based technologies guide sowing depth, fertilizer application, and irrigation in CA systems, improving efficiency and reducing waste.

7.4 CA and Integrated Pest Management (IPM)

Diversified rotations and habitat management in CA help suppress pests and diseases naturally, reducing pesticide use.

8. Barriers to Adoption of Conservation Agriculture

8.1 Socioeconomic and Cultural Constraints

1) Limited awareness of long-term benefits
2) Risk aversion among smallholder farmers
3) Lack of secure land tenure and policy support
4) High labor or machinery costs for initial implementation

8.2 Technical and Biophysical Barriers

1) Weed pressure under no-till systems
2) Residue management challenges in rice-based systems
3) Crop-specific suitability and yield trade-offs in the early years
4) Pest and rodent issues under mulch-covered fields

8.3 Institutional and Policy-Level Issues

1) Input subsidy schemes favor conventional agriculture
2) Weak extension networks for CA promotion
3) Limited access to credit or carbon finance mechanisms

9. Strategic Interventions for Scaling Conservation Agriculture

9.1 Research and Development

1) Develop region-specific CA packages with crop combinations and mechanization
2) Invest in bio-based herbicides and weed-suppressing cover crops
3) Conduct long-term trials to quantify yield and carbon benefits

9.2 Capacity Building and Farmer Education

1) Strengthen field demonstrations, Farmer Field Schools, and ICT tools
2) Create farmer-to-farmer networks for knowledge sharing

9.3 Policy and Institutional Support

1) Redesign subsidies to favor CA-compatible inputs and machinery
2) Offer incentives for carbon sequestration through result-based financing
3) Include CA in national climate adaptation and soil health strategies

9.4 Public-Private Partnerships

1) Collaborate with agri-businesses for residue-based energy, machinery services, and sustainable value chains
2) Leverage CSR initiatives for CA training and equipment access

9.5 Monitoring and Evaluation

1) Establish frameworks to track CA adoption, soil health parameters, and socioeconomic outcomes
2) Integrate satellite-based tools and farmer feedback for real-time impact assessment

10. Future Outlook and Research Needs

The success of CA in transforming agriculture hinges on localized adaptation, sustained support, and interdisciplinary research. Key priorities include:

- **Soil microbiome characterization** under CA systems
- **Climate-smart CA models** integrating water, nutrient, and pest dynamics
- **Socioeconomic research** on adoption behavior and gender perspectives
- **Quantification of ecosystem services** such as pollination, pest regulation, and carbon sequestration
- **Incentive models** for smallholders to adopt CA, such as payments for ecosystem services (PES)

11. Conclusion

Conservation Agriculture is more than a set of practices—it is a systems-based approach that regenerates degraded soils, enhances biodiversity, builds climate resilience, and sustains food systems. Its emphasis on working with natural processes makes it essential in the global transition toward sustainable agriculture. By improving soil structure, organic matter content, and biological activity, CA not only ensures long-term productivity but also restores ecological functions critical for planetary health.

To realize its full potential, a concerted effort is needed from policymakers, researchers, extension systems, and farmers. Scaling CA requires enabling policies, incentives, participatory research, and integration with digital and ecological innovations. With these steps, CA can lead the way in securing a sustainable and equitable future for agriculture and the environment.

References

Cárceles Rodríguez, B., Durán-Zuazo, V. H., Soriano Rodríguez, M., García-Tejero, I. F., Gálvez Ruiz, B., & Cuadros Tavira, S. (2022). Conservation agriculture as a sustainable system for soil health: A review. *Soil Systems*, *6*(4), 87.

M. Tahat, M., M. Alananbeh, K., A. Othman, Y., & I. Leskovar, D. (2020). Soil health and sustainable agriculture. *Sustainability*, *12*(12), 4859.

Verhulst, N., Govaerts, B., Verachtert, E., Castellanos-Navarrete, A., Mezzalama, M., Wall, P., ... & Sayre, K. D. (2010). Conservation agriculture, improving soil quality for sustainable production systems. *Advances in soil science: food security and soil quality*, *1799267585*, 137-208.

Reicosky, D. (2020). Conservation agriculture systems: Soil health and landscape management. In *Advances in conservation agriculture* (pp. 87-154). Burleigh Dodds Science Publishing.

Yadav, M. R., Parihar, C. M., Kumar, R., Yadav, R. K., Jat, S. L., Singh, A. K., ... & Jat, M. L. (2017). Conservation agriculture and soil quality–an overview. *Int. J. Curr. Microbiol. Appl. Sci*, *6*, 1-28.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Impact of Rising CO_2 Levels and Temperature on Plant Physiology: Adaptation and Mitigation Strategies

[1]Santosh Kumar Meena, [2]Anant Vyas, [3]Samridhya Mukherjee,

[1]M.Sc. Scholar, Department of Plant Physiology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi

[2]M.Sc. Scholar, Department of Plant Physiology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi

[3]M.Sc. Scholar, Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi

Abstract

Climate change, largely driven by anthropogenic greenhouse gas emissions, is causing significant increases in atmospheric carbon dioxide (CO_2) concentrations and global temperatures. These two factors while interconnected have complex and often contrasting effects on plant physiology. Elevated CO_2 may stimulate photosynthesis and water use efficiency in some species, while rising temperatures can impair reproductive development, reduce yields, and exacerbate water and nutrient stress. The interaction between these factors affects plant growth, metabolism, phenology, and ecosystem dynamics. This paper presents a comprehensive review of how elevated CO_2 and high temperatures affect plant physiology, highlighting the adaptive responses of plants and proposing mitigation strategies to ensure sustainable crop production in a changing climate.

Keywords: Elevated CO_2, Global Warming, Photosynthesis, Temperature Stress, Plant Adaptation, Climate-Resilient Crops, Mitigation Strategies, Agricultural Sustainability

1. Introduction

Climate change is one of the most pressing challenges facing global agriculture in the 21st century. The continued rise in atmospheric carbon dioxide (CO_2) levels currently exceeding 420 parts per million (ppm) and global temperatures, which have already increased by more than 1.2°C since pre-industrial times, are significantly altering agroecosystems. Plants, being primary producers and sensitive indicators of environmental change, respond directly to fluctuations in atmospheric CO_2 and temperature.

Understanding these responses is essential for devising effective strategies to adapt and mitigate the adverse impacts on food security. While elevated CO_2 may initially enhance plant growth and yield (especially in C_3 species), the concurrent rise in temperature can negate these benefits by accelerating senescence, reducing pollen viability, and intensifying drought and heat stress. This paper delves into the multifaceted effects of CO_2 and temperature changes on plant physiology, examines adaptation strategies in plants, and discusses mitigation approaches suited for climate-resilient agriculture.

2. Physiological Impact of Elevated CO_2 on Plants

2.1 Photosynthetic Enhancement and Carbon Assimilation

Elevated CO_2 concentrations improve photosynthesis by increasing the substrate availability for Rubisco, the enzyme responsible for carbon fixation in the Calvin cycle. In C_3 plants (e.g., rice, wheat, soybean), photorespiration-a wasteful process is reduced under high CO_2, leading to a net gain in carbon assimilation. Studies have shown that elevated CO_2 can increase photosynthetic rates by 20–40%, resulting in higher biomass accumulation.

However, C_4 plants (e.g., maize, sorghum), which possess a CO_2-concentrating mechanism, show only modest improvements since their photosynthesis is already saturated at current CO_2 levels.

2.2 Stomatal Conductance and Water Use Efficiency (WUE)

One consistent physiological response to elevated CO_2 is the partial closure of stomata. This reduces stomatal conductance and transpiration, leading to improved WUE. Plants lose less water per unit of carbon fixed, a trait especially valuable under water-scarce conditions. Enhanced WUE can lead to deeper rooting systems and better drought tolerance.

2.3 Biomass Accumulation and Yield

Elevated CO_2 often leads to increased shoot and root biomass. However, the magnitude of yield improvement depends on other factors, including nutrient availability, pest pressure, and temperature. For example, in Free Air CO_2 Enrichment (FACE) experiments, yields of wheat and rice increased by 10–20% under elevated CO_2, though these gains were often diminished under nutrient or heat stress.

2.4 Nutrient Dilution and Food Quality

Elevated CO_2 can result in a "dilution effect," whereby carbohydrate accumulation outpaces the uptake of essential nutrients like nitrogen, zinc, and iron. This leads to lower protein and micronutrient content in grains and vegetables, raising concerns about the nutritional quality of crops under future climates.

2.5 Effects on Plant Defense Mechanisms

CO_2 enrichment can alter the balance of primary and secondary metabolism. Increased carbon availability may boost the synthesis of some phenolic compounds, while others involved in plant defense might be suppressed. This may influence pest and disease dynamics, requiring re-evaluation of pest management practices.

3. Physiological Effects of Rising Temperature on Plants

3.1 Metabolic Disruption and Enzyme Denaturation

Temperature governs the rate of enzymatic reactions and cellular processes. While a slight increase (within optimal limits) may stimulate growth, temperatures above critical thresholds impair enzyme activity, destabilize proteins, and increase production of reactive oxygen species (ROS), leading to oxidative stress.

3.2 Impacts on Photosynthesis and Respiration

Photosynthesis is particularly sensitive to heat stress. High temperatures reduce chlorophyll content, impair PSII efficiency, and damage thylakoid membranes. Conversely, respiration rates rise exponentially with temperature, increasing carbon loss and reducing net photosynthesis. The combined effect lowers biomass and yield.

3.3 Reproductive Sensitivity and Yield Reduction

The reproductive phase is highly vulnerable to thermal stress. High daytime or nighttime temperatures affect:

- Pollen viability and germination
- Ovule fertility and fertilization success
- Grain size, filling duration, and final yield

In wheat, temperatures above 35°C during anthesis can reduce grain set by over 50%. In rice, spikelet sterility is a major concern during hot weather.

3.4 Membrane Stability and Cellular Damage

High temperatures alter the lipid composition of membranes, increasing fluidity and permeability. This results in electrolyte leakage, loss of cellular homeostasis, and cell death. Plants produce heat shock proteins (HSPs) to stabilize proteins and protect membranes under stress.

3.5 Accelerated Phenology

Warming accelerates phenological events like flowering and maturity. Shortened grain filling periods result in lower yield and quality. This also disrupts synchrony with pollinators and may expose crops to stress at vulnerable stages.

4. Combined Effects of Elevated CO_2 and Temperature

The interaction between CO_2 enrichment and elevated temperature is not additive; it is often antagonistic. Elevated CO_2 can enhance photosynthesis and growth, but these benefits may be nullified by temperature-induced stress.

For example:

- In soybean, elevated CO_2 increased biomass, but high temperatures reduced seed set.
- In wheat, CO_2 improved vegetative growth, but heat stress at grain filling reduced yield significantly.

Thus, plant responses depend on the severity, timing, and duration of temperature stress, and the crop species involved.

5. Adaptive Responses of Plants to CO_2 and Temperature Stress

5.1 Morphological Adaptations

- Leaf rolling and orientation reduce light interception and overheating.
- Thick cuticles and increased trichome density help conserve water.

- Deep root systems enhance water uptake from subsoil layers.

5.2 Biochemical and Physiological Adaptations

- Accumulation of osmoprotectants (e.g., proline, sugars) maintains cell turgor.
- Enhanced antioxidant defense (e.g., SOD, CAT, peroxidases) mitigates oxidative damage.
- Upregulation of HSPs and chaperone proteins stabilizes protein structures.

5.3 Genetic and Epigenetic Mechanisms

Plants exhibit transgenerational stress memory through epigenetic modifications like DNA methylation and histone acetylation. These changes regulate gene expression involved in stress tolerance.

5.4 Phenological Shifts

Some plants adjust their life cycle to avoid stress periods, such as early flowering or shortened vegetative phases an adaptive but yield-limiting response.

6. Mitigation Strategies for Climate-Resilient Agriculture

6.1 Agronomic Interventions

6.1.1 Adjusting Sowing and Harvesting Times

Altering planting dates helps crops escape heat during sensitive stages (e.g., flowering). Crop calendars must be revised based on local climate projections.

6.1.2 Conservation Agriculture

Practices like minimum tillage, cover cropping, and residue retention improve soil health, reduce temperature extremes, and enhance moisture retention.

6.1.3 Mulching and Shade Nets

Mulching moderates soil temperature and reduces evaporation. Shade nets in horticulture help prevent heat injury and sunscald.

6.2 Genetic and Biotechnological Approaches

6.2.1 Conventional Breeding

Screening and selecting heat-tolerant genotypes, such as those with superior root systems or stay-green traits, is essential.

6.2.2 Marker-Assisted Selection (MAS)

Markers linked to heat-responsive QTLs (e.g., canopy temperature depression, chlorophyll fluorescence) facilitate precision breeding.

6.2.3 Genetic Engineering and Genome Editing

Transgenic crops expressing genes like HSPs, DREB transcription factors, and ROS scavengers have shown enhanced tolerance. CRISPR/Cas9 allows targeted editing of heat-sensitivity genes.

6.3 Technological Innovations

6.3.1 Controlled Environment Agriculture (CEA)

Greenhouses, hydroponics, and vertical farms allow temperature and CO_2 control, ensuring productivity even under adverse climates.

6.3.2 Precision Agriculture

Use of drones, IoT sensors, and satellite data helps monitor crop status, guide irrigation, and detect heat stress in real-time.

6.4 Integrated Water and Nutrient Management

6.4.1 Efficient Irrigation Systems

Drip and sprinkler irrigation reduce water use and prevent heat-induced wilting.

6.4.2 Balanced Fertilization

CO_2-enhanced growth requires proportional increases in nutrients, particularly nitrogen. Site-specific nutrient management ensures optimal uptake.

6.5 Ecosystem-Based Strategies

6.5.1 Agroforestry

Integration of trees improves microclimate, reduces temperature extremes, and sequesters carbon.

6.5.2 Crop Diversification

Rotations involving legumes, millets, and cover crops enhance system resilience and reduce risk.

6.5.3 Organic Matter Management

Adding compost and biochar improves soil buffering capacity against temperature fluctuations.

7. Role of Policy, Education, and Research

1) **Capacity Building**: Training farmers and extension agents on climate-smart practices.
2) **Research Funding**: Encouraging interdisciplinary studies on CO_2-temperature-plant interactions.
3) **Infrastructure Support**: Promoting access to irrigation, quality seeds, and early warning systems.
4) **Carbon Credits and Incentives**: Supporting climate mitigation through afforestation, conservation farming, and low-emission inputs.

8. Future Outlook and Research Needs

1) **Crop Simulation Models**: Need for region-specific models integrating genotype × environment × management interactions.
2) **Systems Biology Approaches**: Understanding regulatory networks in stress signaling pathways.
3) **Microbiome Engineering**: Leveraging plant-microbe interactions to improve stress tolerance.
4) **Socioeconomic Analysis**: Evaluating the cost-benefit and adoption barriers for smallholder farmers.

9. Conclusion

The rising levels of atmospheric CO_2 and temperature represent a dual-edged sword for plant physiology and agriculture. While elevated CO_2 may promote growth and water efficiency in the short term, the negative impacts of heat stress, nutrient dilution, and phenological disruption threaten long-term productivity and food security. Plants exhibit a range of physiological and molecular adaptations to cope with these challenges, but the limits of such resilience are being tested under rapidly changing climates.

A multifaceted approach combining improved crop genetics, precision agronomy, climate-smart practices, and supportive policies is essential to mitigate the adverse impacts and harness potential benefits. Future agricultural strategies must be forward-looking, inclusive, and grounded in interdisciplinary science to ensure sustainability in the face of climate uncertainty.

References

Zaib, M., Zeeshan, A., Akram, H., Amjad, W., Aslam, S., & Qasim, S. (2023). Impact of climate change on crop physiology and adaptation strategies: A review. *Int Res J Educ Technol (IRJEdT)*, *5*(08), 17.

Malhi, G. S., Kaur, M., & Kaushik, P. (2021). Impact of climate change on agriculture and its mitigation strategies: A review. *Sustainability*, *13*(3), 1318.

Raza, A., Razzaq, A., Mehmood, S. S., Zou, X., Zhang, X., Lv, Y., & Xu, J. (2019). Impact of climate change on crops adaptation and strategies to tackle its outcome: A review. *Plants*, *8*(2), 34.

Roy, S., Kapoor, R., & Mathur, P. (2024). Revisiting changes in growth, physiology and stress responses of plants under the effect of enhanced CO2 and temperature. *Plant and Cell Physiology*, *65*(1), 4-19.

AbdElgawad, H., Zinta, G., Beemster, G. T., Janssens, I. A., & Asard, H. (2016). Future climate CO2 levels mitigate stress impact on plants: increased defense or decreased challenge?. *Frontiers in plant science*, *7*, 556.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

The Role of Plant Growth Regulators in Optimizing Physiological Processes and Crop Performance

[1]Anant Vyas, [2]Santosh Kumar Meena, [3]Samridhya Mukherjee

[1]M.Sc. Scholar, Department of Plant Physiology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi
[2]M.Sc. Scholar, Department of Plant Physiology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi
[3]M.Sc. Scholar, Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi

Abstract

Plant Growth Regulators (PGRs) are organic compounds that significantly influence plant growth, development, and stress responses. These regulators, either synthesized naturally within plants (phytohormones) or applied exogenously, play a crucial role in enhancing crop productivity, improving stress tolerance, and optimizing physiological processes such as germination, flowering, fruiting, and senescence. This paper reviews the classification, mechanisms, and applications of PGRs in modern agriculture, emphasizing their role in improving crop performance under varying environmental conditions. Furthermore, the potential benefits and challenges associated with PGR usage are discussed, along with future perspectives for sustainable agricultural practices.

Keywords: Plant Growth Regulators (PGRs), Phytohormones, Crop Productivity, Stress Tolerance, Physiological Processes

1. Introduction

Agriculture faces increasing challenges due to climate change, soil degradation, and growing food demand. To address these issues, researchers and agronomists have explored various strategies to enhance crop yield and resilience. Among these, Plant Growth Regulators (PGRs) have emerged as vital tools for optimizing plant physiological processes and improving agricultural output.

PGRs are bioactive molecules that regulate plant growth and development at low concentrations. They can be naturally occurring (endogenous hormones) or synthetically produced (exogenous regulators). By modulating cellular activities, PGRs influence processes such as seed germination, root and shoot development, flowering, fruit setting, and stress responses.

This paper examines the major classes of PGRs, their physiological roles, and their applications in agriculture. Additionally, it discusses the benefits and limitations of PGR usage and explores future research directions for maximizing crop performance sustainably.

2. Classification of Plant Growth Regulators

Plant Growth Regulators (PGRs) are classified into five major groups based on their chemical structure and physiological roles. These include **auxins, gibberellins, cytokinins, abscisic acid, and ethylene**, along with newer classes like **brassinosteroids, jasmonates, and strigolactones**.

2.1 Auxins

Biosynthesis:

- Primarily synthesized in **shoot apical meristems, young leaves, and developing seeds**.
- Derived from tryptophan via the **indole-3-pyruvic acid pathway**.

Examples:

- Natural: Indole-3-acetic acid (IAA), Indole-3-butyric acid (IBA)
- Synthetic: Naphthalene acetic acid (NAA), 2,4-Dichlorophenoxyacetic acid (2,4-D)

Physiological Functions:

1. **Cell Elongation:** Auxins induce proton pump activation, loosening cell walls for expansion (acid growth hypothesis).

2. **Root Initiation:** Used in horticulture for **rooting cuttings** (IBA and NAA are common in commercial formulations).
3. **Apical Dominance:** Suppress lateral bud growth, ensuring vertical growth (high auxin-to-cytokinin ratio).
4. **Fruit Development:** Prevent **premature fruit drop** in apples and tomatoes via auxin sprays.
5. **Phototropism & Gravitropism:** Redistribute auxin to mediate bending toward light (phototropism) or gravity (gravitropism).

Agricultural Applications:

- **Weed control** (2,4-D as a selective herbicide).
- **Tissue culture** for micropropagation.

2.2 Gibberellins (GAs)

Biosynthesis: Produced in **young leaves, roots, and seeds** via the terpenoid pathway.

Examples: Bioactive forms: GA_1, GA_3 (Gibberellic acid), GA_4.

Physiological Functions:

1. **Stem Elongation:** Overcome dwarfism in plants (e.g., GA-treated wheat exhibits taller growth).
2. **Seed Germination:** Activate **α-amylase** in cereal seeds (e.g., barley malt production).
3. **Fruit Growth:** Increase berry size in seedless grapes ("Thompson Seedless" treated with GA_3).
4. **Flowering Induction:** Substitute for cold/fotoperiod requirements in biennials (e.g., cabbage).

Agricultural Uses:

- **Malting industry** (accelerated germination in barley).
- **Parthenocarpy** (seedless fruit production).

2.3 Cytokinins

Biosynthesis: Synthesized in **root tips** and transported via xylem.

Examples: Natural: Zeatin (most abundant in plants), Isopentenyladenine (IPA) and Synthetic: Kinetin, Benzyladenine (BA).

Physiological Roles:

1. **Cell Division:** Synergize with auxins in **callus formation** (tissue culture).
2. **Delay Senescence:** Retain chlorophyll in leafy vegetables ("green stay" effect).
3. **Nutrient Mobilization:** Create "sink" tissues by attracting nutrients (e.g., cytokinin-sprayed leaves retain nutrients longer).
4. **Stress Mitigation:** Enhance drought tolerance by promoting root growth.

Applications:

- **Micropropagation** (shoot multiplication).
- **Post-harvest freshness** (used on cut flowers and greens).

2.4 Abscisic Acid (ABA)

Biosynthesis: Produced in **stressed leaves, roots, and mature seeds**.

Functions:

1. **Stomatal Regulation:** Triggers stomatal closure under drought (via guard cell signaling).
2. **Seed Dormancy:** Maintains dormancy until favorable conditions (broken by gibberellins).
3. **Stress Adaptation:** Upregulates **stress-responsive genes** (e.g., LEA proteins in desiccation tolerance).

Agricultural Relevance: Drought-resistant crops (ABA-primed seeds show better survival).

2.5 Ethylene

Unique Properties: Only **gaseous hormone**, synthesized from methionine.

Functions:

1. **Fruit Ripening:** Climacteric fruits (e.g., bananas, tomatoes) exhibit ethylene-induced respiration spikes.
2. **Senescence & Abscission:** Shedding of leaves (used in mechanical cotton harvesting).
3. **Stress Response:** Aerenchyma formation in waterlogged roots.

Commercial Uses:

- **Ethephon** (ethylene-releasing agent) for uniform fruit ripening.
- **1-MCP** (ethylene inhibitor) to extend shelf life.

2.6 Emerging PGRs

1. **Brassinosteroids:** Enhance **photosynthesis** and **heat tolerance** (e.g., 24-epibrassinolide in tomato).
2. **Jasmonates:** Defense against **herbivores** (induce nicotine in tobacco).
3. **Strigolactones:** Promote **mycorrhizal symbiosis** and inhibit lateral branching.

Table 1: PGRs and Their Roles

PGR Class	Major Function	Agricultural Use
Auxins	Rooting, apical dominance	Rooting powders, herbicides
Gibberellins	Stem elongation, seed germination	Fruit enlargement, malt production
Cytokinins	Delayed senescence, cell division	Tissue culture, post-harvest management
ABA	Stress tolerance, dormancy	Drought-resistant crops
Ethylene	Fruit ripening, abscission	Harvest aids, ripening agents

3. Applications of PGRs in Agriculture

3.1 Enhancing Crop Yield

- **Gibberellins** increase sugarcane yield by elongating internodes.
- **Auxins** improve fruit retention in tomatoes and apples.

3.2 Improving Stress Resistance

- **ABA-treated crops** show better survival under drought.
- **Brassinosteroids** mitigate heavy metal toxicity in plants.

3.3 Post-Harvest Management

- **Ethylene inhibitors** (e.g., 1-MCP) extend shelf life of fruits.
- **Cytokinins** delay leaf yellowing in cut flowers.

3.4 Organic and Sustainable Farming

- **Seaweed extracts** (natural PGR sources) improve soil health.
- **Microbial-derived PGRs** (e.g., rhizobacteria) enhance nutrient uptake.

4. Challenges and Future Perspectives

4.1 Challenges

- **Overuse risks:** Hormonal imbalance, phytotoxicity.
- **Environmental concerns:** Residual effects on ecosystems.
- **High costs:** Synthetic PGRs may be expensive for small farmers.

4.2 Future Research Directions

- **Precision application techniques** (nanotechnology, controlled-release formulations).
- **Genetic engineering** for endogenous PGR optimization.
- **Eco-friendly PGR alternatives** (bio-stimulants, microbial inoculants).

5. Modes of Application and Dosage Optimization

PGRs are applied through various methods depending on crop type and desired effect:

- **Foliar Spray**: Common for vegetative and reproductive enhancement.
- **Soil Drenching**: Used for root uptake and long-term effects.
- **Seed Treatment**: Improves germination and early vigor.
- **Fruit Dipping or Injection**: For uniform ripening and size enhancement.

The timing, concentration, and frequency must be optimized to avoid phytotoxicity and ensure efficacy.

6. Challenges and Limitations in PGR Use

Despite their benefits, several constraints hinder the widespread adoption of PGRs:

- ✓ **Phytotoxicity**: Over-application or improper timing can lead to growth inhibition or abnormal development.
- ✓ **Environmental Concerns**: Residual effects on soil microflora and ecological balance are areas of concern.
- ✓ **Regulatory Issues**: Variability in approval and labeling across regions affects standardization.
- ✓ **Economic Constraints**: High cost and limited access reduce adoption among smallholder farmers.

7. Recent Advances and Future Prospects

7.1 Nano-formulations and Slow-release PGRs

Nano-encapsulation improves the stability and targeted delivery of PGRs, minimizing wastage and environmental risks.

7.2 Genetic Engineering and Hormonal Pathways

CRISPR and other gene-editing tools are being explored to modify hormonal pathways for enhanced yield and stress tolerance.

7.3 Integration with Precision Agriculture

Remote sensing and AI-based tools are being used to guide PGR application based on real-time crop health indicators.

7.4 Sustainable PGRs

Research is ongoing to develop biodegradable, eco-friendly PGRs derived from natural plant extracts and microbes.

8. Conclusion

Plant Growth Regulators play a pivotal role in orchestrating plant physiology and development, thereby directly influencing crop yield and quality. Their judicious use, tailored to crop needs and environmental conditions, can significantly enhance agricultural productivity. While challenges persist in terms of cost, awareness, and regulation, emerging technologies promise more efficient and sustainable use of PGRs in modern farming systems. Integration of PGRs with precision agriculture, biotechnology, and organic practices holds great promise for achieving global food security in an environmentally responsible manner.

9. References

1. Sabagh, A. E., Mbarki, S., Hossain, A., Iqbal, M. A., Islam, M. S., Raza, A., ... & Farooq, M. (2021). Potential role of plant growth regulators in administering crucial processes against abiotic stresses. *Frontiers in Agronomy*, *3*, 648694.

2. Pan, S., Rasul, F., Li, W., Tian, H., Mo, Z., Duan, M., & Tang, X. (2013). Roles of plant growth regulators on yield, grain qualities and antioxidant enzyme activities in super hybrid rice (Oryza sativa L.). *Rice*, *6*(1), 9.

3. Rademacher, W. (2015). Plant growth regulators: backgrounds and uses in plant production. *Journal of plant growth regulation*, *34*(4), 845-872.

4. EL Sabagh, A., Islam, M. S., Hossain, A., Iqbal, M. A., Mubeen, M., Waleed, M., ... & Abdelhamid, M. T. (2022). Phytohormones as growth regulators during abiotic stress tolerance in plants. *Frontiers in Agronomy*, *4*, 765068.

5. Desta, B., & Amare, G. (2021). Paclobutrazol as a plant growth regulator. *Chemical and Biological Technologies in Agriculture*, *8*(1), 1.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Hydroponics in Urban Agriculture: A Sustainable Approach to Vegetable Production

V.K. Maheshwari

Ph.D. Research Scholar, Department of Vegetable science, Ravindranath Tagore University, Raisen, Madhya Pradesh

Abstract

Urbanization, climate change, and the degradation of agricultural land have created significant challenges for conventional food production systems. In this context, hydroponics is a method of growing plants without soil using nutrient-rich water. Its has emerged as a promising solution for sustainable vegetable production in urban environments. Hydroponics maximizes yield per unit area, conserves water, reduces the need for pesticides, and enables year-round cultivation. This paper explores the scientific foundations of hydroponics, its integration into urban agriculture, benefits, limitations, system types, economic viability, and potential role in achieving sustainable food systems. With a growing global population and increasing urbanization, hydroponics stands as a powerful tool to ensure food security, improve nutrition, and promote sustainable urban living.

Keywords: Hydroponics, Urban Agriculture, Soilless Cultivation, Vegetable Production, Sustainability, Food Security, Controlled Environment Agriculture, Smart Farming

1. Introduction

The global population is projected to reach nearly 10 billion by 2050, with over two-thirds residing in urban areas. This demographic shift is placing unprecedented pressure on agricultural systems to produce more food using fewer resources. Conventional agriculture is struggling to meet these demands due to shrinking arable land, water scarcity, environmental degradation, and climate variability. Urban agriculture has thus gained momentum as a means to shorten supply chains, reduce transportation emissions, and enhance food security.

Hydroponics, a soilless cultivation technique, represents a key innovation in this shift. It allows for controlled, efficient, and high-density vegetable production in non-traditional spaces such as rooftops, balconies, greenhouses, and warehouses. The ability to grow food closer to consumers, regardless of soil quality or climatic conditions, makes hydroponics particularly valuable in urban settings.

This paper critically examines hydroponics as a sustainable and scalable solution to urban vegetable production, detailing its mechanisms, applications, environmental impact, technical requirements, and future potential.

2. Scientific Principles and System Types in Hydroponics

2.1 Scientific Foundations

Hydroponics relies on a fundamental principle: plants do not require soil itself but the nutrients that soil provides. In hydroponics, plants receive a precisely balanced nutrient solution dissolved in water, which directly reaches their roots. The essential components include:

1. **Macronutrients** – Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), and Sulfur (S)
2. **Micronutrients** – Iron (Fe), Zinc (Zn), Copper (Cu), Manganese (Mn), Molybdenum (Mo), Boron (B), and Chlorine (Cl)

In hydroponic systems, pH and electrical conductivity (EC) are regularly monitored to ensure optimal nutrient uptake.

2.2 Major Types of Hydroponic Systems

1. **Nutrient Film Technique (NFT):** A shallow stream of nutrient solution is continuously circulated over plant roots housed in sloped channels. It's ideal for leafy vegetables and herbs.

2. **Deep Water Culture (DWC):** Plants are suspended in a nutrient solution with their roots fully submerged. Oxygen is supplied using air pumps and stones to prevent root suffocation.
3. **Ebb and Flow System (Flood and Drain):** Nutrient solution floods the plant tray at intervals, then drains back into the reservoir. It allows periodic wetting and aeration of the roots.
4. **Wick System:** Passive and simple, this system uses a wick to draw nutrient solution from a reservoir to the plant roots. It suits small-scale, low-maintenance setups.
5. **Drip System:** Delivers nutrient solution directly to the root zone through drip emitters. It can be either recirculating or non-recirculating.
6. **Aeroponics:** Roots are suspended in air and intermittently misted with nutrient solution. High oxygen availability to roots makes this system highly efficient.

3. Benefits of Hydroponics in Urban Vegetable Production

3.1 Optimized Land Use and Vertical Farming: Hydroponics enables cultivation in locations previously considered unsuitable for agriculture. Vertical farming systems, which stack layers of crops, dramatically increase yield per square meter. This spatial efficiency is critical in high-density urban areas with limited land availability.

3.2 Water Efficiency and Conservation: Hydroponics uses up to 90% less water than soil-based agriculture. The closed-loop design minimizes evaporation, and excess water is recaptured and reused. This conservation is crucial in water-scarce regions and aligns with global sustainability goals.

3.3 Year-Round Production: Controlled environment agriculture (CEA) allows hydroponic systems to function independent of seasonal and climatic changes. This consistency ensures stable supply and market availability of fresh produce.

3.4 Faster Growth and Higher Yields: Precise nutrient delivery and optimal environmental control enhance photosynthesis and growth rates. Crops mature 25–50% faster and achieve higher yields compared to conventional farming.

3.5 Reduced Pest and Disease Pressure: The absence of soil eliminates soil-borne pathogens. Enclosed systems protect plants from many external pests, reducing the need for chemical pesticides and contributing to healthier produce.

3.6 Urban Food Security and Freshness: Hydroponics reduces dependency on long supply chains by bringing production closer to consumption points. It ensures fresher vegetables with fewer losses during storage and transportation.

3.7 Sustainable and Eco-Friendly: Hydroponics minimizes land degradation, reduces carbon footprints, and allows integration with renewable energy and waste recycling systems — promoting circular urban economies.

4. Suitable Crops for Hydroponic Systems

Certain vegetables and herbs are particularly suited for hydroponic cultivation due to their root structure, growth cycle, and nutritional needs. Common crops include:

1. **Leafy Greens** – Lettuce, spinach, Swiss chard, kale
2. **Herbs** – Basil, coriander, parsley, mint
3. **Fruit Vegetables** – Tomatoes, cucumbers, peppers, chillies
4. **Microgreens** – Mustard, beet, radish, broccoli sprouts
5. **Others** – Strawberries, bush beans, eggplants (in advanced systems)

These crops are chosen for their quick turnover, high market value, and adaptability to hydroponic conditions.

5. Components and Infrastructure of Hydroponic Systems

5.1 Structural and Operational Requirements

To operate a hydroponic system successfully, several components must be in place:

1. **Grow Beds or Channels** – Support the plant and hold the root system
2. **Reservoir Tank** – Stores the nutrient solution
3. **Water Pump** – Circulates nutrients through the system
4. **Aeration System** – Provides oxygen to roots (air pump and stone)
5. **Growing Media** – Inert support like perlite, vermiculite, or coco coir
6. **Artificial Lighting** – LED grow lights are essential in indoor farms
7. **Climate Control Systems** – Regulate temperature, humidity, and CO_2 levels

5.2 Monitoring Tools

1. **pH Meters** – Maintain the nutrient solution within optimal pH (5.5–6.5)
2. **EC Meters** – Measure electrical conductivity, indicating nutrient concentration
3. **Timers and Controllers** – Automate lighting and irrigation schedules
4. **Sensors and IoT Devices** – Enable real-time monitoring and smart control

6. Environmental and Sustainability Impacts

6.1 Climate Change Mitigation: Hydroponics reduces the need for land conversion, preventing deforestation and preserving biodiversity. It also minimizes methane and nitrous oxide emissions associated with soil-based farming.

6.2 Efficient Resource Use: Nutrient and water recirculation systems eliminate runoff and reduce nutrient leaching, a common cause of waterway pollution in traditional agriculture.

6.3 Integration with Renewable Energy: Hydroponic systems can be powered by solar or wind energy, further reducing carbon emissions and supporting energy independence.

6.4 Waste Reduction and Circularity: Organic waste from hydroponic farms can be composted or integrated into aquaponics systems, where fish waste serves as a nutrient source for plants.

7. Socio-Economic Implications

7.1 Urban Livelihoods and Employment: Hydroponic farming creates employment opportunities in design, installation, production, marketing, and education. It supports small-scale entrepreneurs and urban youth in agri-tech sectors.

7.2 Empowerment through Decentralization: Hydroponics allows households, schools, and communities to grow their own food, reducing dependency and increasing food sovereignty.

7.3 Educational and Therapeutic Applications: Hydroponics is used in STEM education and therapeutic horticulture programs. Schools integrate hydroponic labs to teach sustainability and biology.

8. Limitations and Challenges

Despite its advantages, hydroponics also faces certain limitations:

8.1 High Initial Capital Costs: Setting up hydroponic infrastructure — especially climate-controlled systems — involves significant investment, making it less accessible to low-income communities without subsidies or credit access.

8.2 Technical Complexity: Successful operation requires knowledge of plant physiology, water chemistry, and system engineering. A lack of trained personnel can lead to crop failure.

8.3 Energy Requirements: Indoor systems rely on artificial lighting and climate control, increasing electricity demand. Integration with renewables is essential to maintain sustainability.

8.4 Limited Crop Diversity: Root crops (e.g., carrots, onions, potatoes) are less compatible with standard hydroponic systems due to their morphology and space requirements.

8.5 Policy and Regulatory Constraints: In many cities, land use policies, zoning regulations, and lack of urban agriculture guidelines hinder the widespread adoption of hydroponics.

9. Economic Viability and Investment Considerations

9.1 Cost Structure

1. **Capital Expenditure (CapEx)** – Infrastructure, grow lights, sensors, control systems
2. **Operational Expenditure (OpEx)** – Nutrients, electricity, labor, water

9.2 Profitability Drivers

1. Choice of high-value crops
2. Local market demand and direct-to-consumer models
3. Use of automation and smart systems to reduce labor costs
4. Partnerships with restaurants, grocery stores, and subscription services

Hydroponics is especially profitable in urban areas where land prices are high, and fresh produce commands a premium.

10. Technological Integration for Smart Urban Farming

Hydroponics is increasingly integrating with digital tools to enhance productivity:

1. **IoT and Smart Sensors** – Monitor and control nutrient levels, humidity, temperature, and lighting

2. **AI and Machine Learning** – Optimize nutrient dosing, detect plant stress, and predict yield
3. **Mobile Applications** – Offer user interfaces for farmers to manage and troubleshoot remotely
4. **Blockchain** – Ensures traceability of food supply, increasing consumer confidence

These advancements transform hydroponics into a high-tech solution aligned with future urban development.

13. Conclusion

Hydroponics offers a sustainable, scalable, and technologically advanced solution to meet the food demands of urban populations. By enabling efficient and localized vegetable production, hydroponics contributes significantly to food security, climate resilience, and urban sustainability. While challenges related to costs, energy, and policy remain, the integration of smart technologies, supportive governance, and increased public awareness can overcome these barriers. As cities continue to expand, hydroponics stands poised to play a critical role in shaping the future of food in an increasingly urbanized world.

14. References

Rufí-Salís, M., Calvo, M. J., Petit-Boix, A., Villalba, G., & Gabarrell, X. (2020). Exploring nutrient recovery from hydroponics in urban agriculture: An environmental assessment. *Resources, Conservation and Recycling*, *155*, 104683.

Rafee, B. M., Zaheed, S. M., Devi, Y. S., Asan, J., Jakith, A. A., Ahamed, R. S., ... & Commerce, B. (2023). A RISE OF HYDROPONICS THE FUTURE URBAN FARMING AND SUSTAINABILITY OF AGRICULTURE–AN OVERVIEW. *Journal of Research Administration*, *5*(2), 8325-8336.

Shilpa, Sharma, P., & Bansuli. (2024). Hydroponics in vegetable crops: A review. *Hydroponics: The Future of Sustainable Farming*, 15-41.

Rajaseger, G., Chan, K. L., Tan, K. Y., Ramasamy, S., Khin, M. C., Amaladoss, A., & Haribhai, P. K. (2023). Hydroponics: current trends in sustainable crop production. *Bioinformation*, *19*(9), 925.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Role of Crop Rotation in Enhancing Soil Fertility and Maintaining Yield Stability

[1]Hans Raj Meel, [2]Supreet Kaur, [3]Rohitash Meena, [4]Aakash Kumar Saini

[1]Ph.D. Scholar, Department of Soil Science, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur

[2]M. Sc. Scholar, Department of Agronomy, Punjab Agricultural University, Ludhiana

[3]M.Sc. Scholar, Division of Agronomy, Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior

[4]Ph.D. Scholar, Department of Soil Science, ICAR- Indian Institute of Soil Science, Bhopal

Abstract

Crop rotation, a time-tested agricultural practice, involves growing different types of crops sequentially on the same piece of land. This method enhances soil fertility, breaks pest and disease cycles, and stabilizes crop yields. In the modern context of degraded soils, excessive fertilizer use, pesticide resistance, and climate variability, crop rotation offers an ecologically sound and economically viable solution to sustainable farming. This paper elaborates on the mechanisms of crop rotation in nutrient cycling, biological health, and yield consistency. It also discusses its comparative advantages over monoculture systems, examines its implementation challenges, and outlines strategies for widespread adoption. By integrating agroecological knowledge with modern innovations, crop rotation can serve as a powerful pillar of sustainable agricultural systems.

Keywords: Crop rotation, soil fertility, yield stability, sustainable agriculture, pest and disease management, nutrient cycling, soil health, biodiversity

1. Introduction

Sustainable agriculture demands an efficient use of natural resources while ensuring long-term productivity and ecological balance. However, continuous monocropping, high input dependency, and declining soil health have placed modern farming under stress. Crop rotation, whereby different crop species are grown on the same field in a planned sequence. It can mitigate many of these problems by naturally enriching the soil, disrupting pest cycles, and maintaining system productivity.

Historically, crop rotation has been embedded in traditional farming practices. Farmers rotated cereals with legumes or fallowed land to allow for natural recovery. While industrial agriculture temporarily shifted the focus to monocultures supported by synthetic inputs, the adverse consequences such as soil nutrient mining, groundwater pollution, pest outbreaks, and yield decline have reignited interest in crop rotation. Scientific evidence now supports the significant role of rotation in improving soil structure, nutrient availability, microbial biodiversity, and overall crop performance.

This paper aims to provide a comprehensive analysis of the role crop rotation plays in enhancing soil fertility and stabilizing yields, exploring both the theoretical underpinnings and practical applications.

2. Principles and Types of Crop Rotation

2.1 Fundamental Principles of Crop Rotation

1. Botanical Diversity: Rotating crops from different plant families helps avoid the buildup of host-specific pests and diseases.
2. Root System Variation: Alternating deep- and shallow-rooted crops improves nutrient extraction from different soil layers and enhances soil structure.
3. Legume Inclusion: Incorporating legumes in the rotation cycle boosts nitrogen levels via biological fixation.
4. Seasonal Balance: Crop selection based on growth season (e.g., kharif, rabi, zaid) ensures efficient land use and reduces weed dominance.
5. Residue Management: Each crop’s residue quality affects subsequent nutrient release and microbial activity.

2.2 Types of Crop Rotation Systems

1. Simple Rotations: Involve two or three crops (e.g., maize–legume, wheat–pulses).

ISSN : 3048 - 989X

2. Complex Rotations: Use four or more crops, including cereals, legumes, tubers, oilseeds, and vegetables.
3. Temporal Rotations: Planned based on time—annual, biennial, or longer cycles.
4. Spatial Rotations: Practiced over different plots within a farm to optimize land use.

Examples include:

- Rice–Wheat–Green Gram
- Cotton–Chickpea–Sorghum
- Soybean–Maize–Sunflower

3. Crop Rotation and Soil Fertility Enhancement

3.1 Improved Nutrient Cycling

Rotational cropping enhances nutrient balance through:

1. Nitrogen Fixation: Legumes like chickpea, cowpea, and groundnut fix atmospheric nitrogen via Rhizobium bacteria, reducing synthetic N demand.
2. Nutrient Mining and Redistribution: Deep-rooted crops like sunflower and safflower bring up nutrients from subsoil layers for use by subsequent shallow-rooted crops.
3. Organic Matter Inputs: Different crops contribute varied residue types (high or low C:N ratio), influencing soil carbon and microbial activity.
4. Reduced Nutrient Leaching: Cover crops reduce nutrient runoff and immobilize nitrates.

3.2 Physical Soil Improvement

1. Soil Structure: Fibrous root systems improve aggregation and reduce erosion.
2. Porosity and Infiltration: Rotation with crops like sorghum enhances soil porosity and water infiltration.
3. Compaction Mitigation: Crops with deep taproots break up compact layers.

3.3 Enhanced Soil Biological Activity

1. Microbial Biomass and Diversity: Root exudates from various crops feed different microbial populations, leading to a more diverse and active soil food web.
2. Soil Enzyme Activity: Increased due to microbial stimulation, aiding nutrient transformations.
3. Symbiotic Associations: Crop-specific arbuscular mycorrhizal fungi improve phosphorus uptake and stress resistance.

4. Crop Rotation and Yield Stability

4.1 Breaking Pest and Disease Cycles

Crop rotation disrupts the habitat and food sources of specific pathogens and pests:

1. Reduced Soil-Borne Pathogens: Rotation prevents the buildup of Fusarium, Verticillium, and nematodes.
2. Delayed Resistance Development: Avoids the repeated selection pressure on pest populations, reducing pesticide resistance.
3. Reduced Need for Pesticides: Economically and environmentally beneficial.

4.2 Weed Management

Different crops influence weed emergence due to variation in:

1. Canopy cover
2. Planting and harvesting times
3. Allelopathic effects

Weed seedbanks are reduced over time, especially when cover crops like mustard or cowpea are used.

4.3 Buffer Against Climatic Variability

Rotation adds resilience:

1. Drought-resistant crops in dry years
2. Nitrogen-fixing crops in nutrient-poor soils
3. Quick-growing crops in short-season windows

4.4 Improved Resource Use Efficiency

Crops with varying water and nutrient demands optimize the use of irrigation and fertilizer resources across seasons.

4.5 Sustainable Yield Trends

Empirical studies show that well-designed crop rotations outperform monocultures in: Long-term yield stability, Profitability, Input efficiency

5. Comparative Benefits Over Monoculture

5.1 Ecological Benefits

1. Biodiversity Conservation: Enhances soil, insect, and microbial diversity.
2. Reduced GHG Emissions: Less fertilizer and pesticide use lowers carbon footprint.
3. Soil Regeneration: Maintains ecosystem services such as nutrient cycling, water regulation, and carbon sequestration.

5.2 Economic Benefits

1. Lower Input Costs: Reduced need for fertilizers and pesticides.
2. Diversified Income: Multiple crops buffer farmers against market and climate shocks.
3. Market Expansion: Opens opportunities for legumes, oilseeds, and niche vegetables.

5.3 Social and Community Benefits

1. Food and Nutritional Security: Produces a variety of food crops.
2. Job Creation: Seasonal diversity increases labor demand.
3. Empowerment: Promotes indigenous knowledge and women's participation in agriculture.

6. Key Factors Affecting Crop Rotation Effectiveness

6.1 Agro-Ecological Suitability such as Soil type (clay, loamy, sandy), Rainfall pattern and irrigation availability and Temperature and frost sensitivity

6.2 Farm Size and Mechanization like Smallholders may face land constraints and Mechanization allows diverse crops with precision tools

6.3 Input Availability

6.4 Knowledge and Extension Gaps

6.5 Institutional and Policy Support

7. Constraints to Adoption of Crop Rotation

1. Cultural Inertia: Farmers habituated to single crops may resist change.
2. Market Risks: Lack of assured price support for non-staple crops.
3. Labor Shortages: Diverse crops may need skilled labor at different times.
4. Seed Supply Bottlenecks: Especially for niche pulses and oilseed varieties.
5. Weather Uncertainty: Rainfall variability affects sowing and harvesting windows.
6. Infrastructure Gaps: Limited access to cold storage, transport, and post-harvest facilities for rotation crops.
7. Financial Risks: Lack of crop insurance and credit access for diversified cropping systems.
8. Research Gaps: Need for location-specific data on optimal rotation sequences and their long-term effects.

8. Strategies to Promote Crop Rotation

8.1 Policy Interventions

1. Include pulses and oilseeds in minimum support price (MSP) programs.
2. Incentives for crop diversification under government schemes.
3. Integrate crop rotation into national soil health and climate adaptation strategies.

8.2 Extension and Training

1. Demonstrations of rotation benefits.
2. Crop calendars and guidance materials.
3. Farmer field schools and mobile advisory apps.
4. Community-led planning of rotational schemes.

8.3 Research and Innovation

1. Region-specific cropping sequences.
2. Improved varieties of legume and minor crops.
3. Development of short-duration and climate-resilient crops.
4. Digital tools for precision planning.

8.4 Market Linkages and Incentives

1. Contract farming and value chain development.
2. Agro-processing and local consumption of rotational crops.
3. Certification and branding of sustainable rotational products.

9. Integration with Other Sustainable Practices

9.1 Conservation Agriculture
9.2 Organic Farming
9.3 Agroforestry Systems
9.4 Climate-Smart Agriculture
9.5 Integrated Nutrient Management
9.6 Integrated Pest Management

10. Future Prospects and Research Needs

1. Digital Tools: Decision support systems for rotation planning using GIS and AI.
2. Carbon Markets: Payment for ecosystem services (e.g., soil carbon from legumes).
3. Public-Private Partnerships: Seed banks, training, and R&D collaborations.
4. Gender Perspectives: Understand women's role in crop management and decision-making.
5. Policy Mainstreaming: Crop rotation as a core component in national agricultural missions.
6. Long-Term Field Trials: To quantify benefits under different agro-ecological zones.
7. International Cooperation: Share success models and technologies across countries.
8. Education Curricula: Include rotation science in agronomy and extension education.

11. Conclusion

Crop rotation represents a powerful tool for achieving sustainable agricultural systems. Its ability to regenerate soil fertility, manage pests and weeds, and ensure stable yields makes it indispensable in both conventional and organic farming systems. Though challenges to its adoption remain, a supportive policy environment, scientific innovation, and farmer education can transform crop rotation from a traditional practice to a modern strategy for resilient agriculture. Given the growing demand for food security and environmental protection, crop rotation must be embraced as a foundational pillar of agroecological intensification.

By integrating crop rotation with modern practices like conservation agriculture, digital farming, and climate-smart policies, it is possible to build a future-ready agriculture that sustains the environment, supports livelihoods, and secures nutrition for all.

12. References

Shah, K. K., Modi, B., Pandey, H. P., Subedi, A., Aryal, G., Pandey, M., & Shrestha, J. (2021). Diversified crop rotation: an approach for sustainable agriculture production. *Advances in Agriculture*, *2021*(1), 8924087.

Ouda, S., Zohry, A., & Noreldin, T. (2018). Crop rotation maintains soil sustainability. In *Crop Rotation: An Approach to Secure Future Food* (pp. 55-76). Cham: Springer International Publishing.

Bullock, D. G. (1992). Crop rotation. *Critical reviews in plant sciences*, *11*(4), 309-326.

Li, J., Huang, L., Zhang, J., Coulter, J. A., Li, L., & Gan, Y. (2019). Diversifying crop rotation improves system robustness. *Agronomy for Sustainable Development*, *39*(4), 38.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Beneficial Microbes: The Hidden Allies in Crop Protection

SUPRIYA, S[1]., PANKAJA, N. S[2]. AND SUNITHA MUMMINENI[1]

[1]Ph. D. Scholar, Department of Plant Pathology, College of Agriculture V. C. Farm, Mandya, UAS, GKVK, Bangalore, Karnataka, India

[2]Associate Professor Department of Plant Pathology, College of Agriculture V. C. Farm, Mandya, UAS, GKVK, Bangalore, Karnataka, India

Abstract

In the battle against crop diseases and pests, beneficial microbes have emerged as powerful, eco-friendly allies in sustainable agriculture. These microscopic organisms, ranging from bacteria and fungi to actinomycetes and yeasts, play crucial roles in enhancing plant growth, suppressing pathogens, and improving soil health. Unlike chemical pesticides, beneficial microbes offer a natural mode of action by inducing plant resistance, outcompeting harmful microbes, and producing antimicrobial compounds. Key examples include *Trichoderma* spp., *Bacillus* spp., and *Pseudomonas fluorescens*, all of which are widely recognized for their biocontrol properties. Additionally, symbiotic microbes, such as mycorrhizae and rhizobia, help plants access essential nutrients, thereby increasing their resilience to environmental stress. As concerns about chemical residues and soil degradation grow, the integration of beneficial microbes into crop protection strategies is gaining momentum globally. With continued research and innovation, microbial solutions can significantly reduce dependency on synthetic inputs, ensuring a safer and more sustainable food production system. This article examines how these "hidden allies" are revolutionizing modern agriculture, providing not only protection but also promoting holistic plant health and long-term productivity.

Keywords: Beneficial microbes; Biocontrol agents; Sustainable agriculture; Plant-microbe interactions; Crop protection; Soil health

Introduction

The escalating challenges of global food security, climate change, and increasing resistance to chemical pesticides have accelerated the search for sustainable and environmentally friendly approaches in agriculture. Among these, the use of beneficial microbes, also known as plant growth-promoting microorganisms (PGPMs) has emerged as a promising alternative to conventional agrochemicals. These microbes colonize various niches around and within plants, including the rhizosphere, endosphere, and phyllosphere, and are capable of enhancing plant health, growth, and immunity through multifaceted interactions (Compant et al., 2005; Vurukonda et al., 2016).

Beneficial microbes encompass a wide variety of organisms such as bacteria (e.g., *Bacillus*, *Pseudomonas*), fungi (e.g., *Trichoderma*, mycorrhizal fungi), and actinomycetes, each employing distinct and often synergistic mechanisms. These include induced systemic resistance (ISR), production of antibiotics and lytic enzymes, nutrient solubilization (especially phosphorus and potassium), siderophore production for iron acquisition, and competitive exclusion of pathogens (Lugtenberg & Kamilova, 2009; Glick, 2012; Pieterse et al., 2014).

For instance, *Trichoderma harzianum* is known not only for its mycoparasitic activity against fungal pathogens but also for its ability to stimulate plant growth and defense pathways (Harman et al., 2004). Similarly, *Pseudomonas fluorescens* and *Bacillus subtilis* are widely used biocontrol agents, producing an array of secondary metabolites that inhibit a broad spectrum of phytopathogens while simultaneously enhancing root development and stress tolerance (Kloepper et al., 2004; Perez-García et al., 2011).

Recent advances in metagenomics and microbiome engineering have further highlighted the potential of manipulating the plant-associated microbiome to improve crop productivity and disease resilience. Studies suggest that tailored microbial consortia could be applied to specific crops and environments, leading to more precise and effective crop protection strategies (Berg et al., 2017; Toju et al., 2018).

As the demand for residue-free produce and sustainable farming practices grows, the integration of beneficial microbes into mainstream agriculture offers a viable solution. Their role is not limited to disease suppression but extends to soil fertility enhancement, abiotic stress mitigation, and overall plant vigor, making them vital components in the development of resilient agro-ecosystems. In the pursuit of sustainable agriculture, beneficial microbes are revolutionizing crop protection with their remarkable ability to promote plant health, suppress diseases, and improve soil fertility naturally and safely. Unlike synthetic pesticides, these microbes work holistically: improving plant nutrition, enhancing resilience, and actively inhibiting pathogen invasion. This article explores their significance, how they work, and what recent research reveals about their field-level effectiveness.

Trichoderma spp. – The Fungal Bodyguard

Species of *Trichoderma* are well-known antagonists of phytopathogenic fungi and are extensively used in biocontrol strategies across the globe. They exhibit mechanisms such as mycoparasitism, enzyme secretion (e.g., chitinases, β-1,3-glucanases), and competition for space and nutrients. More importantly, *Trichoderma* can colonize root surfaces and induce systemic resistance (ISR) in plants via signalling molecules such as jasmonic acid and salicylic acid pathways (Harman et al., 2004). A study by Sharma et al. (2021) demonstrated that *Trichoderma harzianum* seed treatment effectively reduced damping-off disease in tomato, improving seedling survival and vigor. In rice, *Trichoderma viride* has shown to suppress *Rhizoctonia solani*, the causal agent of sheath blight, by disrupting fungal hyphae and inducing resistance-related enzymes (Singh et al., 2019)

Pseudomonas fluorescens – The Root Protector

Pseudomonas fluorescens is a versatile plant growth-promoting rhizobacterium (PGPR) known for its ability to colonize roots, produce siderophores, antibiotics, hydrogen cyanide, and enzymes like proteases and cellulases. It plays a key role in inducing systemic resistance and suppressing soil-borne pathogens such as *Pythium*, *Fusarium*, and *Magnaporthe oryzae* (Weller, 2007). Field trials by Ramesh et al. (2020) confirmed that *P. fluorescens* reduced rice blast disease severity by over 40%, while enhancing crop yield. The bacterium also facilitates phosphate solubilization, iron acquisition, and mitigates abiotic stresses such as salinity and drought (Kloepper et al., 2004; Saharan & Nehra, 2011).

Bacillus subtilis – The Versatile Defender

Bacillus subtilis stands out due to its spore-forming nature, ensuring long-term viability under field conditions. It synthesizes a broad spectrum of lipopeptides surfactins, iturins, and fengycins, which have antifungal, antibacterial, and surfactant properties that inhibit spore germination and fungal growth (Ongena & Jacques, 2008). According to Verma et al. (2022), *B. subtilis*-based bioformulations effectively managed leaf spot in groundnut, outperforming chemical fungicides. Other studies have reported that it enhances crop resistance by boosting phenolic compounds, pathogenesis-related (PR) proteins, and defensive enzyme activities such as peroxidase and polyphenol oxidase (Chowdhury et al., 2015).

Azospirillum and *Azotobacter* – The Nutrient Boosters

Besides disease suppression, microbes like *Azospirillum brasilense* and *Azotobacter chroococcum* play vital roles in biological nitrogen fixation and phytohormone production (auxins, gibberellins). Their consistent application improves root development, chlorophyll content, and crop biomass (Vessey, 2003). In maize and wheat, inoculation with *Azospirillum* has led to improved nitrogen uptake and resistance to lodging. Similarly, *Azotobacter* not only enhances soil fertility but also suppresses soil pathogens by competing for nutrients and space (Rokhzadi et al., 2008).

Arbuscular Mycorrhizal Fungi – The Underground Network

Arbuscular mycorrhizal fungi (AMF) such as *Glomus intraradices* form symbiotic associations with over 80% of terrestrial plant species. These fungi enhance phosphorus uptake, water absorption, and increase resistance to root pathogens like *Fusarium oxysporum* and *Phytophthora* spp. (Smith & Read, 2008). Studies have shown that AMF colonization leads to enhanced plant immunity via improved signaling pathways and stress tolerance, particularly in drought-prone environments (Pozo & Azcon-Aguilar, 2007; Chandanie et al., 2006).

Microbial Consortia – Strength in Unity

Research now increasingly supports the use of microbial consortia combinations of bacteria and fungi which often show synergistic effects in promoting plant health. For instance, a combined application of *Trichoderma* +

Pseudomonas + *Bacillus* has proven more effective in suppressing diseases and improving plant performance than single strains alone (Mishra et al., 2013). Such consortia not only increase biocontrol efficacy, but also improve nutrient cycling**,** soil structure, and carbon sequestration, contributing to overall agroecosystem resilience**.**

A Green Revolution Driven by Microbes

As agriculture transitions into the age of precision and sustainability, beneficial microbes offer a biologically sound and cost-effective alternative to agrochemicals. Biopesticides and biofertilizers based on microbial formulations are now being commercialized and included in Integrated Pest Management (IPM) programs in many countries. India, for instance, has recognized multiple microbial products under the Insecticides Act**,** paving the way for wide-scale adoption (ICAR, 2020). Moreover, technological advances in genomics, metabolomics, and formulation science are making microbial products more effective**,** stable, and crop-specific. With rising concerns over chemical residues**,** soil degradation, and pathogen resistance, microbial allies are emerging as key players in shaping the future of food and farming.

Discussion

Beneficial microbes form the cornerstone of biologically based plant protection, offering a suite of multifaceted mechanisms to suppress plant pathogens and enhance crop resilience. These mechanisms include antibiosis, competition, parasitism, induced systemic resistance (ISR), and growth promotion. Unlike synthetic pesticides, which often target a narrow spectrum and degrade over time, beneficial microbes create a dynamic, self-sustaining ecological shield around the plant. They are increasingly viewed not only as protectants but also as ecosystem engineers, improving both plant and soil health in the long run.

1. Antibiosis: Nature's Chemical Arsenal

One of the most studied microbial modes of action is antibiosis, where microbes secrete antimicrobial metabolites that inhibit or kill pathogens. For instance, Pseudomonas fluorescens produces antibiotics like 2,4-diacetylphloroglucinol (DAPG), pyoluteorin, and phenazine that are lethal to a wide range of fungal and bacterial pathogens (Weller, 2007). Similarly, Bacillus subtilis synthesizes lipopeptides such as surfactin, iturin, and fengycin, which disrupt the cell membranes of pathogens (Ongena & Jacques, 2008). A study by Chowdhury et al. (2015) demonstrated that *B. subtilis* FZB42 was effective in controlling *Fusarium oxysporum* in tomato through lipopeptide-mediated antibiosis. These natural antimicrobials are biodegradable, leaving no toxic residues and posing minimal risk to non-target organisms an essential trait for sustainable agriculture.

2. Competition: Outnumbering the Enemy

Microbes also compete with pathogens for space and nutrients in the rhizosphere. Fast-colonizing beneficial microbes like *Trichoderma harzianum* and *Pseudomonas spp.* can establish dominant populations that limit pathogen establishment through competitive exclusion. For example, Lugtenberg and Kamilova (2009) noted that plant growth-promoting rhizobacteria (PGPRs) suppress pathogens by monopolizing root exudates and micronutrients such as iron via siderophore production, thereby starving competing pathogens. This passive yet powerful mechanism is particularly effective against soil-borne diseases such as wilt, rot, and blight.

3. Parasitism: Direct Pathogen Destruction

Mycoparasitism is a specific form of biocontrol exhibited by fungi like *Trichoderma spp.*, which directly parasitize pathogenic fungi. This involves the secretion of cell wall-degrading enzymes such as chitinases, β-1,3-glucanases, and proteases, which break down the structural components of the pathogen. Harman et al. (2004) reported that *T. harzianum* not only degraded the hyphae of *Rhizoctonia solani* but also formed coils around them, leading to complete lysis of the pathogen. This direct antagonism has been effectively used in managing root and collar rot in a variety of crops, including legumes, cereals, and vegetables.

4. Induced Resistance: Priming the Plant Immune System

One of the most ecologically significant modes of microbial action is induced systemic resistance (ISR). Beneficial microbes trigger plant defense pathways, activating genes associated with pathogenesis-related (PR) proteins, phenolic compounds, peroxidase, polyphenol oxidase, and PAL (phenylalanine ammonia lyase). Pieterse et al. (2014) highlighted that ISR is mediated through the jasmonic acid (JA) and ethylene (ET) signalling pathways, enhancing the plant's ability to resist future infections. For example, Ramesh et al. (2020) found that *P. fluorescens* application in rice not only suppressed blast disease but also increased PR protein levels and phenolic accumulation. This pre-activation of the plant immune system is especially valuable under field conditions, where multiple pathogens may pose threats simultaneously. The ISR mechanism provides broad-spectrum protection without direct confrontation with pathogens.

5. Growth Promotion: Beyond Defense

Beyond disease control, beneficial microbes actively enhance plant growth. They improve nutrient acquisition through phosphorus solubilization, potassium mobilization, and nitrogen fixation. Microbes like *Azospirillum* and *Azotobacter* fix atmospheric nitrogen, while *Bacillus* and *Pseudomonas* species produce indole-3-acetic acid (IAA) and gibberellins, promoting root elongation and shoot growth (Vessey, 2003; Saharan & Nehra, 2011). Choudhary and Johri (2009) demonstrated that co-inoculation with *Azotobacter chroococcum* and *Pseudomonas fluorescens* significantly improved chlorophyll content, biomass, and yield in wheat under low-input conditions. These growth-promoting attributes reduce the dependence on chemical fertilizers, making the entire production cycle more economically and ecologically viable.

6. Building Biodiversity and Climate Resilience

Perhaps the most transformative impact of beneficial microbes lies in their ability to restore soil biodiversity and build climate resilience. Long-term use of synthetic pesticides often depletes soil microbial diversity, leading to imbalances and pathogen dominance. Beneficial microbes help reverse this trend by recolonizing soil niches, improving soil structure, and supporting carbon sequestration (Berg et al., 2017). Additionally, microbial inoculants improve plant tolerance to drought, salinity, and heat stress by enhancing osmoprotectant production and antioxidant activity (Vurukonda et al., 2016). This is crucial in the face of increasing climate variability, where abiotic stress is as threatening to crop productivity as biotic stress.

Conclusion

Beneficial microbes are more than just biological alternatives to chemical pesticides they represent a fundamental shift in the way we approach crop protection and agricultural sustainability. These invisible allies work in harmony with plants and ecosystems, offering multifaceted benefits such as disease suppression, enhanced nutrient uptake, stress tolerance, and long-term soil health improvement. By harnessing mechanisms like antibiosis, competition, parasitism, and induced resistance, these microbes provide a dynamic and resilient shield against plant pathogens, all while enriching biodiversity and reducing our ecological footprint. As global agriculture grapples with challenges such as pesticide resistance, climate variability, soil degradation, and food security, the integration of beneficial microbes offers a holistic, low-input, and eco-friendly solution. Unlike conventional practices that often address problems in isolation, microbial interventions promote systemic health, fortifying the plant, the soil, and the surrounding environment.

The road ahead lies in scaling up microbial technologies through advances in metagenomics, formulation science, and microbial consortia design tailored to specific crops, climates, and farming systems. Widespread adoption will depend on effective extension services, policy incentives, and farmer training that demystifies their use and highlights their long-term value. Ultimately, embracing beneficial microbes is not just about protecting crops it's about redefining agriculture for the 21st century. It's about moving toward a future where productivity is in sync with ecology, where farmers are empowered with nature-based tools, and where food systems are resilient, safe, and sustainable. In this new paradigm, beneficial microbes are not just supporting actors—they are essential agents of change, quietly leading the next green revolution—rooted in biology, not in chemistry.

References

Berg, G., Rybakova, D., Grube, M., & Köberl, M. (2017). The plant microbiome explored: Implications for experimental botany. *Journal of Experimental Botany*, 68(16), 4011–4026.

Chandanie, W. A., Kubota, M., & Hyakumachi, M. (2006). Interactions between plant growth promoting fungi and arbuscular mycorrhizal fungi and their significance for disease resistance. *Soil Biology and Biochemistry*, 38(5), 847–854.

Choudhary, D. K., & Johri, B. N. (2009). Interactions of Bacillus spp. and plants–with special reference to induced systemic resistance (ISR). *Microbiological Research*, 164(5), 493–513.

Chowdhury, S. P., Hartmann, A., Gao, X., & Borriss, R. (2015). Biocontrol mechanism by root-associated *Bacillus amyloliquefaciens* FZB42: a review. *Frontiers in Microbiology*, 6, 780.

Compant, S., Duffy, B., Nowak, J., Clément, C., & Barka, E. A. (2005). Use of plant growth-promoting bacteria for biocontrol of plant diseases: Principles, mechanisms of action, and future prospects. *Applied and Environmental Microbiology*, 71(9), 4951–4959.
Glick, B. R. (2012). Plant growth-promoting bacteria: Mechanisms and applications. *Scientifica*, 2012, Article ID 963401.
Harman, G. E. et al. (2004). Trichoderma species—opportunistic avirulent plant symbionts. *Nature Reviews Microbiology*, 2, 43–56.
ICAR (2020). Handbook of Bioagents and Biopesticides. Indian Council of Agricultural Research.
Kloepper, J. W., Ryu, C. M., & Zhang, S. (2004). Induced systemic resistance and promotion of plant growth by *Bacillus* spp. *Phytopathology*, 94(11), 1259–1266.
Lugtenberg, B., & Kamilova, F. (2009). Plant-growth-promoting rhizobacteria. *Annual Review of Microbiology*, 63, 541–556.
Mishra, D. S., Singh, A., & Saxena, A. K. (2013). Biocontrol consortium for suppression of plant pathogens: A promising ecofriendly approach. *Indian Phytopathology*, 66(2), 203–206.
Ongena, M., & Jacques, P. (2008). Bacillus lipopeptides: Versatile weapons for plant disease biocontrol. *Trends in Microbiology*, 16(3), 115–125.
Perez-García, A., Romero, D., & de Vicente, A. (2011). Plant protection and growth stimulation by microorganisms: Biotechnological applications of Bacilli in agriculture. *Current Opinion in Biotechnology*, 22(2), 187–193.
Pieterse, C. M. J., Zamioudis, C., Berendsen, R. L., et al. (2014). Induced systemic resistance by beneficial microbes. *Annual Review of Phytopathology*, 52, 347–375.
Pozo, M. J., & Azcon-Aguilar, C. (2007). Unraveling mycorrhiza-induced resistance. *Current Opinion in Plant Biology*, 10(4), 393–398.
Ramesh, M., Aravind, R., & Deepa, N. (2020). Effect of *Pseudomonas fluorescens* on suppression of rice blast and yield improvement. *Indian Journal of Agricultural Sciences*, 90(5), 842–847.
Ramesh, R., et al. (2020). Suppression of rice blast disease through *Pseudomonas fluorescens*. *Indian Phytopathology*, 73(3), 449–455.
Rokhzadi, A. et al. (2008). Influence of plant growth-promoting rhizobacteria on dry matter accumulation and yield of chickpea. *Journal of Plant Nutrition*, 31(10), 1585–1597.
Saharan, B. S., & Nehra, V. (2011). Plant growth promoting rhizobacteria: A critical review. *Life Sciences and Medicine Research*, 21(1), 1–30.
Sharma, R., Kaur, P., & Singh, A. (2021). Biocontrol potential of *Trichoderma harzianum* in suppressing damping-off in tomato. *Journal of Plant Pathology*, 103(3), 765–772.
Singh, R. et al. (2019). Biocontrol efficacy of *Trichoderma viride* against *Rhizoctonia solani* in rice. *Journal of Applied and Natural Science*, 11(2), 386–391.
Smith, S. E., & Read, D. J. (2008). *Mycorrhizal Symbiosis* (3rd ed.). Academic Press.
Toju, H., Peay, K. G., Yamamichi, M., Narisawa, K., Hiruma, K., & Hiura, T. (2018). Core microbiomes for sustainable agroecosystems. *Nature Plants*, 4(5), 247–257.
Verma, S., et al. (2022). Bioformulated *Bacillus subtilis* for sustainable management of leaf spot in groundnut. *Journal of Plant Disease Science*, 17(2), 123–130.
Vessey, J. K. (2003). Plant growth promoting rhizobacteria as biofertilizers. *Plant and Soil*, 255(2), 571–586.
Vurukonda, S. S. K. P., Vardharajula, S., Shrivastava, M., & SkZ, A. (2016). Enhancement of drought stress tolerance in crops by plant growth-promoting rhizobacteria. *Microbiological Research*, 184, 13–24.
Weller, D. M. (2007). Pseudomonas biocontrol agents of soilborne pathogens: Looking back over 30 years. *Phytopathology*, 97(2), 250–256.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Stingless Bees, Little Bees, and Rock Bees Conservation and Honey Harvest

Kuppuraj. S and K.J. Sivasangari

B.Sc. (Hons.) Agriculture

Department of Agriculture Entomology, Kumaraguru Institute of Agriculture, Erode

Abstract

Bees play an indispensable role in maintaining ecological stability, agricultural productivity, and food security through pollination. In India, indigenous bee species such as stingless bees (Tetragonula spp.), little bees (Apis florea), and rock bees (Apis dorsata) not only support biodiversity but are also vital sources of medicinal and commercial honey. This article explores their unique biological characteristics, habitat preferences, roles in pollination, and traditional and modern honey harvesting practices. Furthermore, it examines the ongoing conservation efforts, threats to their survival, and proposes sustainable strategies to protect these essential pollinators and promote ethical honey production.

Introduction

Bees are among the most critical pollinators on Earth, supporting nearly 75% of the crops used for food. In India, three indigenous bee species stand out due to their unique biology and socioeconomic value: stingless bees (Tetragonula spp.), little bees (Apis florea), and rock bees (Apis dorsata). These bees not only support pollination of native flora and agricultural crops but also produce honey with exceptional medicinal and commercial value. However, increasing environmental degradation, pesticide usage, and unsustainable harvesting have led to a decline in their populations. This study provides a comprehensive overview of their biological traits, ecological importance, honey production practices, and conservation strategies.

Stingless Bees (*Tetragonula spp*.)

Stingless bees, belonging to the genus Tetragonula under the tribe Meliponini, are eusocial insects native to tropical and subtropical regions, including India. Unlike other bees in the family Apidae, they lack functional stingers, relying instead on biting and the secretion of sticky resins (propolis) for defense. Though minute in size—typically 3–5 mm in length— their ecological importance and sophisticated social behavior rival that of larger honey bees.

Biology and Morphology

Stingless bees exhibit the key features of Hymenoptera: compound eyes, three ocelli, segmented antennae, and a modified ovipositor. Their mandibles are strong and adapted for collecting resin, while their hind legs feature pollen baskets (corbiculae), aiding in foraging. Unlike Apis species, their wings are shorter, limiting their foraging range to 500–700 meters.

Caste System and Social Hierarchy

Stingless bee colonies exhibit a highly organized caste system consisting of Queen that has single reproductive female responsible for egg-laying. She mates once and lays up to 200– 300 eggs per day and Workers, a Sterile female performing all tasks—nest building, foraging, nursing, cleaning, and colony defense. Workers undergo age polyethism, where their roles shift with age and Drones, a Male bee whose sole function is mating with virgin queens during nuptial flights. They are short-lived and non-foraging. The caste differentiation is governed by nutrition and pheromonal control. Larvae destined to become queens are fed royal jelly-like substances and placed in special queen cells.

Colony Structure and Nesting Behavior

Stingless bee nests are typically built in hollow logs, tree trunks, wall crevices, bamboo segments, or man-made wooden boxes. The nest comprises: Propolis entrance tube with Sticky, narrow tunnel guarding against predators.

Brood chamber is Composed of horizontal spirals of wax pots where larvae develop.Storage pots are Larger oval-shaped pots made of wax and resin for storing honey and pollen. Waste chamber is Isolated zone for detritus, kept away from brood. These bees use plant resins mixed with wax to build their combs, which also serve antimicrobial functions due to the resin's properties.

Honey Production and Characteristics

Stingless bee honey is often called "medicinal honey" for its potent biochemical profile. It is:

- More watery (high moisture content: ~25–35%)
- Highly acidic (pH 3.2–4.5)
- Rich in phenolics, flavonoids, and organic acids
- Known for antibacterial, anti-inflammatory, antioxidant, and wound-healing properties
- The annual yield is low—typically 300–800 ml per colony—but its high therapeutic value compensates for the quantity. This honey is extensively used in traditional medicine for treating sore throats, ulcers, eye infections, and respiratory problems.

Domestication and Sustainable Harvesting

Meliponiculture (stingless beekeeping) is gaining attention due to the bees' docility, small hive size, and sustainable harvest methods. Honey is extracted using syringes or pipettes without harming the brood. Domesticated hives can be installed in urban backyards, balconies, or orchards. They require minimal management and offer an excellent pollination boost to fruit crops, vegetables, and medicinal plants.

Little Bees (*Apis florea*)

Apis florea, commonly known as the Little Bee, is the smallest member of the honeybee family and an important wild pollinator in South and Southeast Asia. Despite its diminutive size—adults measuring only 7–10 mm—Apis florea plays a critical role in maintaining ecological diversity and pollinating crops like guava, citrus, mango, brinjal, and mustard. These bees are naturally found in open landscapes, agricultural fields, gardens, and forest edges.

Biology and Morphology

Little bees are characterized by their slender reddish-brown bodies, transparent wings, and sparse hair. Their anatomical features include a long proboscis for collecting nectar from small flowers and well-developed pollen baskets (corbiculae) on their hind legs. They thrive in warm, low-altitude environments and are highly efficient foragers with rapid mobility.

Caste System and Colony Structure

- Queen: The sole fertile female, larger than workers, responsible for laying all the eggs in the colony.
- Workers: Sterile females who perform all labor—nest building, foraging, nursing larvae, and colony defense. They exhibit age-based division of labor.
- Drones: Male bees that mate with virgin queens during nuptial flights and die shortly after. They do not contribute to colony maintenance.

Colony size ranges from 2,000 to 10,000 bees, significantly smaller than that of rock bees or European bees. The development of caste differentiation is influenced by diet, pheromonal communication, and colony needs.

Nesting and Behavioral Traits

Unlike other honeybee species, Apis florea constructs a single exposed comb—not in cavities or hives. These nests are built on thin branches, fences, shrubs, and even under roofs or ledges, always in open environments. The comb features:

- A curved structure with brood cells at the center
- Honey and pollen storage cells on the edges
- A protective curtain of worker bees surrounding the entire comb, serving as a living shield
- Little bees are nomadic by nature, often relocating their nests in response to environmental stress, predation, or food shortages. This migratory behavior makes domestication and large-scale beekeeping difficult.

Honey Characteristics and Yield

Little bee honey is lighter in color and milder in flavor compared to Apis dorsata or Tetragonula honey. It contains:

- Lower moisture content than stingless bee honey
- Moderate amounts of antioxidants and glucose
- Good antibacterial activity

The annual honey yield is low—typically 300 to 600 ml per colony, due to the small colony size and single-comb architecture. However, it is highly valued by local communities for its nutritional and medicinal properties, especially for treating sore throats, wounds, and seasonal fevers.

Harvesting Practices and Sustainability

Harvesting is done manually by cutting sections of the comb. In many Indian regions, tribal people collect Apis florea honey using traditional tools like knives or wooden sticks. However, sustainable harvesting requires leaving the brood intact and taking only the outer honey section. Harvesting during early morning or late evening helps reduce stress on the colony. The use of fire or smoke is discouraged, as it causes mass evacuation and colony abandonment. Due to their non-aggressive behavior, little bees rarely sting and are relatively safe to work with. However, their sensitivity to disturbance necessitates careful handling and observation.

Rock Bees (*Apis dorsata*)

Apis dorsata, widely known as the Rock Bee or Giant Honey Bee, is the largest species of honeybee found in South and Southeast Asia. With a robust body size ranging from 17 to 20 mm, these bees are adapted for long-distance foraging and play a significant role in forest pollination and wild honey production. Their powerful flight capability, keen visual navigation, and acute environmental sensitivity make them one of the most ecologically important wild pollinators. These bees thrive in tropical and subtropical climates and are most commonly found nesting on cliffs, tall trees, and sometimes even under the eaves of buildings. Their average lifespan varies, with worker bees surviving around 5–6 weeks, drones living up to three weeks until mating, and queens surviving for several years.

Caste system and Social hierarchy

Rock bee colonies are structured into a highly organized caste system. The queen is the largest bee in the colony and is the sole egg-laying female, capable of producing 1,000 to 1,500 eggs per day. Worker bees are sterile females responsible for all activities within the colony, including brood care, nest building, foraging, hive maintenance, and colony defense. They possess barbed stingers and are highly aggressive in defense, often attacking intruders in swarms. Drones, the male caste, do not engage in labor or foraging. Their sole function is to mate with virgin queens during mating flights, after which they die. Colonies are massive, usually consisting of 30,000 to 60,000 bees, and they display complex social behavior such as the waggle dance for communication and swarm-based migration to follow nectar flows.

Nesting and Behavioral traits

The nesting behavior of Apis dorsata is unique among honeybees. They construct a single, large vertical comb in open air, often suspended from high tree branches or rocky ledges. The comb has a specialized internal structure with clearly divided zones. The central region is the brood area, where eggs, larvae, and pupae develop in wax cells. Adjacent to the brood zone is the pollen storage area, which serves as a protein reserve for feeding larvae. The outermost section consists of capped honey storage cells filled with processed nectar. The bees collect nectar from a wide variety of wildflowers, and through enzymatic processing and moisture evaporation, convert it into honey. Worker bees cap these cells with wax once the honey is mature and ready for storage.

Honey characteristics

The honey produced by rock bees is known for its potent medicinal properties and strong flavor. It is darker in color, more aromatic, and richer in minerals and antioxidants than honey from domesticated species. The moisture content typically ranges from 17% to 20%, with an acidic pH between 3.5 and 4.5. Owing to their large colonies, rock bees can yield 20 to 30 kg of honey per harvest season, making them the largest wild honey producers in

India. Their honey is highly valued in traditional medicine systems, especially in tribal communities and Ayurvedic practices, for treating ailments such as cough, wounds, and digestive disorders.

Honey bee Production and Extraction

Rock bees are known for their highly aggressive defense behavior. They form a protective curtain of bees that constantly fan the nest for ventilation and act as a shield against predators. If disturbed, the colony releases alarm pheromones, triggering mass attacks. Their stings can be fatal in large numbers, which makes honey harvesting from these bees a risky endeavor. Despite their aggressive nature, these bees are crucial for the pollination of forest flora and various commercial crops like cotton, sunflower, and coconut.

Due to their wild nature, Apis dorsata has not been successfully domesticated. Honey is harvested by tribal communities using traditional methods such as night climbing with torches and smoke to disperse the bees. Unfortunately, these techniques often destroy the colony and harm the brood. Sustainable harvesting practices are being promoted through forest-based training programs. These involve minimal smoke use, collecting only the mature honey portions of the comb, and avoiding harvests during breeding seasons.

Conservation and Biodiversity Importance

Conservation of native bee species like stingless bees, little bees, and rock bees requires a holistic and community-centric approach. Habitat preservation is critical, involving the protection of tree hollows, forested areas, cliffs, and natural nesting sites. Restoration of native floral diversity by planting nectar- and pollen-rich species ensures a year-round food source. The excessive use of chemical pesticides poses a severe threat to bee populations; thus, adopting integrated pest management (IPM) techniques and switching to bee-safe alternatives are essential. Community participation is pivotal—training local farmers, tribal groups, and youth in bee-friendly agricultural practices and sustainable harvesting fosters long-term conservation. Forming 'Bee Guardian' groups and community honey cooperatives not only ensures monitoring but also improves livelihoods. Education and awareness programs in schools, villages, and through media can elevate the importance of native pollinators. Moreover, supporting scientific research on bee biology, nesting behavior, and pollination efficiency will help in understanding and preserving their ecological roles. Promoting domestication through wooden bee boxes, especially for stingless bees, is a sustainable solution. Additionally, policy-level support is necessary to regulate wild honey harvesting, protect tribal rights, and offer incentives for eco-friendly beekeeping. Integrating native bees into agroforestry and organic farming practices enhances farm productivity while preserving biodiversity. Establishing pollinator corridors, also known as 'bee highways,' across fragmented landscapes and cultivating flowering field margins further strengthens habitat connectivity. Climate change adaptation through forage planning and protection of water sources is also vital. Finally, providing premium markets, microloans, and certification schemes for sustainably harvested honey can transform conservation efforts into economically viable ventures for rural communities.

Honey Harvesting Techniques

Honey harvesting practices vary greatly across regions and bee species, ranging from highly traditional methods to scientifically refined techniques. In India, honey harvesting is largely species-specific. For stingless bees, especially Tetragonula iridipennis, honey is collected using syringe-based suction or by gently tilting specially designed wooden boxes. This method preserves the brood and structure of the colony. In tribal communities, particularly in Tamil Nadu, honey hunters gather wild honey from rock bees (Apis dorsata) by climbing tall trees or cliffs at night using ropes or ladders, employing smoke to drive bees away. However, this traditional method often results in full comb removal, leading to colony destruction. Awareness is gradually increasing toward sustainable approaches like partial comb harvesting, using minimal smoke, and collecting during non-breeding periods.

In Tamil Nadu, regions like the Nilgiris, Sathyamangalam, and Kalrayan Hills are known for tribal honey collection, where forest-dwelling communities like the Kurumbas and Irulas practice wild honey harvesting. The Tamil Nadu Forest Department and local NGOs have started initiatives to train these communities in ethical harvesting, hygiene, and postharvest honey filtration, enabling value addition and better market access.

Globally, modern beekeeping practices in countries like New Zealand, the U.S., and parts of Europe utilize Langstroth bee boxes for Apis mellifera, allowing frame-by-frame extraction using centrifugal honey extractors.

This ensures non-destructive harvesting and colony continuity. For stingless bees in tropical countries like Brazil, Philippines, and Thailand, horizontal wooden hives with removable honey pots are common. These allow hygienic, medicinal-grade honey extraction with zero harm to brood chambers.

Common global practices now emphasize non-invasive extraction, maintaining bee brood integrity, and using food-grade containers for collection. Use of protective gear, bee smokers, hive tools, and settling tanks for honey processing are standard in organized beekeeping operations. Regulatory bodies also encourage honey harvesting calendars aligned with blooming seasons and bee breeding cycles to avoid overharvesting.

Sustainable Honey Harvesting Techniques

Sustainable honey harvesting techniques prioritize the health and continuity of bee colonies while ensuring hygienic and quality honey extraction. These methods avoid colony destruction, ensure reproductive success, and encourage year-round productivity. For stingless bees, sustainable harvesting involves the use of specially designed wooden hive boxes (log hives or modular boxes) with removable honey pots. Honey is extracted using syringes or suction pumps, avoiding damage to brood chambers. In India, particularly in southern states like Tamil Nadu and Kerala, this method is gaining popularity among smallscale apiculturists due to its simplicity and colony-friendly nature.

For little bees (Apis florea), which are not easily domesticated, sustainable harvesting includes partial comb cutting, where only the honey-storage section is removed, leaving the brood intact. This allows the colony to regenerate without migration. Harvesting is usually done during late evening or early morning hours when bee activity is low, reducing stress.

In the case of rock bees (Apis dorsata), which nest in high, exposed locations, sustainable methods emphasize night-time honey hunting with minimal smoke, using natural repellents like neem or lemongrass oil rather than fire. Only mature honey sections of the comb are harvested, leaving behind the brood and pollen reserves. Using long-handled knives, baskets, and safe climbing gear helps minimize disturbance.

Globally, sustainable practices include the use of Langstroth hives and frame extractors, which allow harvesting without killing bees or destroying combs. Beekeepers are also trained to follow forage calendars, harvesting only during peak nectar flow, and ensuring that bees have enough food and space left post-harvest. Techniques like supering (adding extra boxes above brood chambers) also allow selective honey extraction without colony intrusion.

Additionally, sustainable honey harvesting involves strict hygiene, use of food-grade collection containers, and post-harvest filtration to ensure purity. It discourages the use of harmful chemicals or antibiotics and promotes organic certification. Promoting community training, value addition, and fair trade practices ensures both ecological conservation and economic empowerment of rural beekeepers.

Challenges

The conservation and sustainable management of native bee species—Tetragonula spp. (stingless bees), Apis florea (little bees), and Apis dorsata (rock bees)—face a variety of ecological, social, and technological challenges. For stingless bees, one of the major hurdles is the lack of awareness and scientific understanding of their biology and importance. Despite their docile nature and medicinal honey, they are often overlooked in favor of commercial species like Apis mellifera. Habitat fragmentation, removal of old trees and wall cavities, and pesticide exposure reduce their natural nesting sites. Moreover, improper handling during honey extraction, especially from wild colonies, often leads to destruction of the brood and weakening of colonies. Inadequate training on meliponiculture and lack of standardized harvesting protocols further hinder their domestication and commercial value enhancement.

Little bees (Apis florea), although excellent pollinators of small-flowered crops, face distinct challenges due to their exposed single-comb nesting habit. They frequently build nests on shrubs, fences, and human dwellings, which are often destroyed during cleaning, tree cutting, or construction. Their sensitivity to disturbance, frequent migration, and resistance to domestication make them difficult to integrate into organized apiculture. Additionally, their small colony size results in low honey yield, making them less attractive for commercial honey production, even though their ecological value is immense. Pesticide use and floral resource depletion further impact their populations and nesting cycles.

For rock bees (Apis dorsata), the challenges are more severe due to their wild and aggressive nature. The primary threat lies in destructive traditional honey hunting methods, involving excessive smoke, fire, and full comb removal, which leads to mass bee mortality and colony abandonment. Habitat degradation—especially the felling of tall nesting trees and cliff disturbance—has drastically reduced their natural habitats. Being nondomesticated, they rely entirely on forest ecosystems, making them extremely vulnerable to climate change, deforestation, and human encroachment. Moreover, tribal honey hunters often lack access to scientific training or sustainable harvesting equipment. Policy vacuum and lack of incentives for ethical wild honey collection further compound the threat, with most forest honey sold at undervalued prices through informal markets.

Across all three species, lack of coordinated conservation policies, poor funding for native bee research, and limited public recognition of their pollination and ecological roles continue to undermine efforts for their protection. To ensure long-term viability, integrated strategies combining community awareness, habitat restoration, sustainable beekeeping practices, and market support for ethical honey are essential. Addressing these challenges is not just a matter of biodiversity conservation but also of pollination security, forest health, and livelihood sustainability for rural and indigenous communities.

Conclusion

Stingless bees, little bees, and rock bees are not just honey producers—they are vital ecological agents. Their conservation is essential to maintain biodiversity, enhance food security, and provide livelihoods, especially in rural and tribal communities. Through informed harvesting practices, habitat protection, and community engagement, India can preserve these precious pollinators and continue to benefit from their ecological and economic contributions.

References:

1. Michener, C. D. (2000). The Bees of the World. Johns Hopkins University Press, Baltimore, pp. 827.
2. Roubik, D. W. (1989). Ecology and Natural History of Tropical Bees. Cambridge University Press, Cambridge, pp. 526.
3. Vit, P., Pedro, S. R. M., & Roubik, D. W. (2004). Stingless Bees of Mexico: The Biology, Management and Conservation of an Ancient Bee. Mundi-Prensa, Madrid, pp. 98– 212.
4. Jalil, A. H. (2014). Beescape for Meliponines: Conservation of Indo-Malayan Stingless Bees. Partridge Publishing Singapore, pp. 45–198.
5. Roubik, D. W. (2023). Stingless Bee (Apidae: Apinae: Meliponini) Ecology. Annual Review of Entomology, 68, pp. 231–256.
6. Patharikar, H. A., & Akhare, Y. D. (2022). Physico-chemical Properties of Multi-floral Honey of Apis dorsata from Melghat Region, Maharashtra. Advances in Biodiversity Conservation & Sustainable Development, Shivaji College, pp. 82–90.
7. Mondulkiri Wild Honey. (2024). Traditional Community-Based Apis dorsata Honey Harvesting in Cambodia. ASEAN Heritage Publication, pp. 21–35.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Racing against time: How postharvest innovations are countering climate change's threat to global food security

Usha Nandhini P M

PG Research Scholar, Department of Postharvest Technology, Horticultural College and Research Institute, TNAU, Periyakulam – 625 604

Abstract

Climate change is intensifying postharvest stress, accelerating spoilage and threatening food supply chains. Emerging innovations such as nanotechnology-based coatings, atmospheric modification, and cold plasma treatments are revolutionizing preservation methods. These interventions target microbial load, enzymatic activity, and oxidative damage to extend shelf life and maintain nutrient quality. Integrating IoT-based monitoring enhances precision in storage and transport under volatile climatic conditions. Postharvest science now stands as a critical pillar in global food system resilience.

Keywords: Climate resilience; Postharvest loss; Food security; Smart packaging

1. Introduction

As global temperatures rise and extreme weather events increase, food systems are facing immense pressures, particularly in the postharvest sector. Currently, one-third of food produced globally is lost or wasted, with a significant portion occurring in handling, storage, and distribution. Climate change worsens these losses through accelerated deterioration, pathogen growth, and supply chain disruptions. The UN projects a 50% increase in global food demand by 2050, while climate models predict further degradation of ideal growing conditions. Postharvest innovations offer hope for stabilizing food supplies. Scientists and engineers are developing climate-adaptive technologies to mitigate these challenges.

2. Climate change: The Postharvest amplifier

Accelerated Deterioration Rates

Rising ambient temperatures significantly accelerate biochemical reactions in harvested produce. For every 10°C increase in temperature, respiration rates in fruits and vegetables typically double or triple, dramatically shortening shelf life. Climate change projections indicate average global temperature increases of 1.5-5.8°C by 2100, potentially reducing storage viability periods by 15-30% for many commodities if adaptation measures aren't implemented.

Shifting Pathogen Dynamics

Climate change is reshaping the geographic distribution and virulence of postharvest pathogens. Fungi like *Aspergillus flavus*, which produces dangerous aflatoxins, are expanding into previously inhospitable regions as temperatures warm. Simultaneously, higher humidity levels in some areas create ideal conditions for bacterial proliferation, while drought-stressed crops often show increased susceptibility to postharvest infections.

Disrupted Cold Chains

Extreme weather events, hurricanes, floods, intense heat waves increasingly disrupt electricity supplies and transportation networks critical to maintaining cold chains. A single power outage during a heat wave can destroy massive quantities of refrigerated inventory. As climate models predict more frequent and severe weather events, the resilience of postharvest infrastructure becomes paramount.

3. Adaptive Cold Chain Technologies

Solar-Powered Cooling with Thermal Storage: Integrated systems combining photovoltaic panels with thermal energy storage allow continuous cooling operation throughout nighttime hours and cloudy periods. The Cold Hubs initiative in Nigeria has deployed solar-powered walk-in cold rooms that reduce postharvest losses by up to 80% while operating completely off-grid.

Variable Frequency Drive (VFD) Refrigeration: These systems adjust compressor speeds based on cooling demands, improving energy efficiency by 20-50% while maintaining more precise temperature control during fluctuating external conditions. Their implementation in developing regions faces challenges but could transform cold chain resilience.

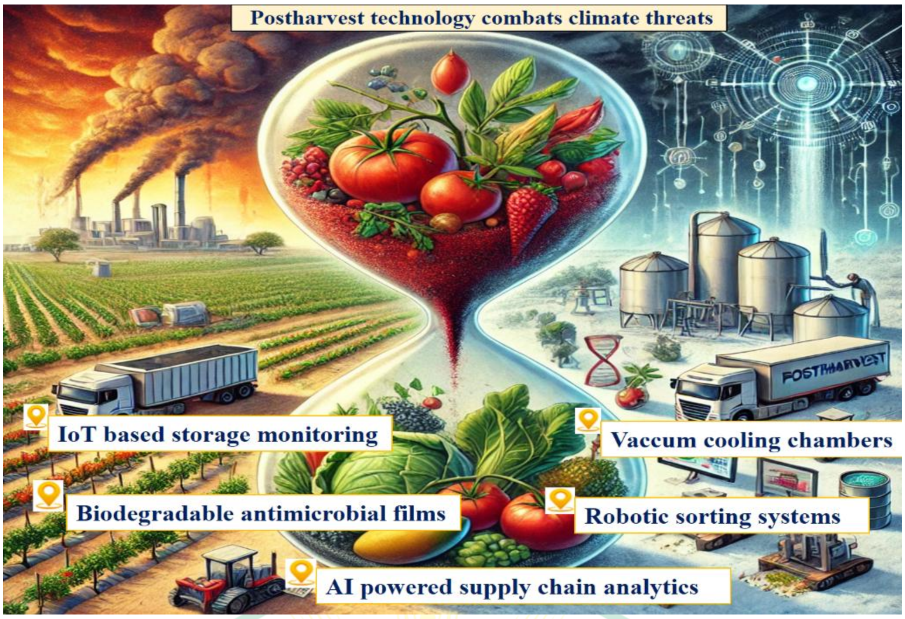


Figure 1. Postharvest innovations countering climate change

4. Smart Packaging Revolution

Modified Atmosphere Packaging (MAP) 2.0: Next-generation MAP technologies incorporate climate-responsive polymers that automatically adjust gas permeability based on ambient temperature fluctuations. This maintains optimal O_2/CO_2 ratios despite variable environmental conditions, extending shelf life by up to 60% compared to conventional MAP.

Nano sensor Integration: Packaging embedded with Nano sensors monitoring ethylene levels, microbial activity, and temperature abuse provides real-time data on product condition. These systems enable dynamic shelf-life prediction algorithms that account for actual storage conditions rather than static timeline estimates.

Edible Coatings with Adaptive Properties: Novel plant-based edible coatings respond to environmental humidity changes, altering their permeability characteristics to maintain optimal moisture levels within the product. These coatings significantly reduce water loss during high-temperature events while preventing condensation during temperature fluctuations.

5. The digital revolution in Postharvest management

Digital Twins for Supply Chain Optimization: Virtual replicas of physical supply chains integrate climate data, infrastructure capabilities, and product physiology models to simulate scenarios and identify vulnerabilities before they occur. Companies implementing these systems report 15-25% reductions in climate-related losses.

Machine Learning for Dynamic Routing: AI-powered logistics platforms analyze weather forecasts, traffic patterns, and product respiration data to continuously optimize transportation routes and storage decisions during climate disruptions. These systems can reroute shipments in real-time to avoid extreme weather events or prioritize facilities with most stable power supplies.

Predictive Quality Algorithms: Advanced algorithms combining product physiology data with environmental sensors can forecast remaining shelf life with unprecedented accuracy, allowing for smarter inventory management and distribution prioritization during climate stress events.

6. Regional adaptations to local climate shift

Arid Region Innovations

Hydro-Powered Evaporative Cooling: The Barsha pump, a hydro-powered water lifting device, combined with clay pot cooling systems provides zero-energy evaporative cooling for small-scale farmers in water-stressed regions. These systems reduce water usage by up to 90% compared to traditional evaporative coolers while maintaining effective temperature reduction.

Desert Refrigeration: Solar-powered refrigeration units specifically designed for extreme heat conditions incorporate advanced insulation materials and thermal management systems that maintain cooling efficiency even as ambient temperatures approach 50°C.

Humid Tropical Adaptations

Dehumidification Systems with Heat Recovery: Energy-efficient dehumidification technologies extract moisture from storage environments while recovering waste heat for water heating or drying applications, addressing both humidity control and energy efficiency challenges in tropical regions.

Mycotoxin-Resistant Storage Systems: Specially designed storage facilities incorporating antimicrobial surfaces, controlled airflow patterns, and humidity regulation prevent the proliferation of aflatoxin-producing fungi increasingly common in warming tropical regions.

Conclusion

The convergence of climate change and postharvest management poses a critical threat to global food security. Effective mitigation hinges on interdisciplinary collaboration among scientists, policymakers, economists, and practitioners. Climate-resilient postharvest technologies must be paired with innovative financing, supportive policies, and scalable implementation strategies. These technologies, once optional, have become vital safeguards against climate-induced losses. While numerous adaptive solutions exist, rapid, context-specific deployment remains the primary challenge. Accelerated innovation and global cooperation are essential to preserving food system resilience. Ensuring postharvest integrity is pivotal in sustaining food security amid escalating climate pressures.

Reference

Paliyath, G., Mattoo, A. K., Handa, A. K., Shetty, K., & Wilson, C. L. (2018). Enhancing food security through postharvest technology: current and future perspectives. Postharvest Biology and Nanotechnology, 1-13.

Srivastava, Y. (2019). Climate change: a challenge for postharvest management, food loss, food quality, and food security. In Climate Change and Agricultural Ecosystems (pp. 355-377). Woodhead Publishing.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Agriculture @79: From Scarcity & Subsistence to Surplus & Exports

Dr. Parveen Kumar

Scientist, KVK-Ramban, SKUAST-j
Main Campus, Chatha, Jammu, Jammu & Kashmir

Defying Malthusian theory that the country's population growth would outstrip food production, Indian agriculture has now moved on from scarcity and subsistence in nature to surplus and exports. As per the third Advance Estimates for the production of major crops for the agricultural year 2024-25, total food grain production is estimated at 353.96 million tonnes (mt). It is India's highest production so far; it is also 40% more than it was one decade ago in 2014-15. The surplus today has been as a result of various pro-farming policies, programmes and various interventions over last seven decades. The green revolution of 1960s led to phenomenal growth in production of food grains. India's dairy, poultry, and fisheries sectors have seen remarkable growth. Similarly, the White Revolution, starting in the 1970s, boosted milk production from 20 mt to 239 mt by 2023-24. The country is also witnessing a surge in production of fisheries leading to blue revolution. Due to the Blue Revolution fish production in the country has increased to 19.5 mt by 2024-25, making India the second-largest seafood producer and exporter. The egg production in the country has now reached 143 billion and poultry meat production from about 1.13 tonnes to five million tonnes over the same period. In the last decade, the agriculture sector has seen an unprecedented growth. Milk production has increased by 10.2 mt annually, broiler meat by 217,000 tonnes and fish by 780,000 (Sh. Shiv Raj Singh Chauhan MoA & FW, GoI).

Before proceeding ahead, let me go to some decades back. After a long and tumultuous struggle that lasted near two decades, the Britishers were forced to declare India as an independent country on Aug. 15, 1947. The day marked the end of foreign dominance and beginning of a new era of self governance and democracy in India. As the country celebrates its 79th Independence Day on August 15, it is also a day to pay rich tributes to the countless freedom fighters, revolutionaries and nationalists who sacrificed their lives for independence of the country. The journey of last more than seven decades has been unique with country progressing by leaps and bounds to become the fifth largest economy in the world at present and posing to become third largest economy in the next few years. Every sector of the economy has witnessed revolutionary strides and the world has felt and observed the positive impacts of this entire phenomenon. The agriculture sector after attaining independence suffered from numerous challenges that include feeding the increasing population, low productivity and stagnation, creating adequate employment opportunities for the surplus labour besides ensuring timely availability of inputs to the farming community. Agriculture sector also suffered because of outdated technology, crude practices and huge dependence on timely rainfall. It was referred to as the 'begging bowl' with major portion of our food requirements being met from imports from other countries. Farmers' of that era were a static entity even reluctant to go for any change in their crude and unscientific cultivation practices. Overhauling the agriculture sector was not possible without ensuring that the relevant technology reached out to farming community well in time as well as motivating the farming community to adopt the new technologies. In all these years of country's journey post independence, the agriculture sector has been the country's strength in its contribution in Gross Domestic Product (GDP) of the country, in providing employment to the population and as a source of livelihood for the vast majority of rural populace.

India from a 'begging bowl' thus changed to a 'bread basket' and the fortune changed by what is known as 'Green revolution'. The period corresponding to 1967-78 witnessed huge upsurge in food grains production especially in states of Punjab Haryana and Uttar Pradesh. Green revolution spread to millions of third world countries also. Reports reveal that the absolute number of poors came down from 1.15 billion in 1975 to 825 million in 1995. All this happened despite a 60 per cent growth in population. Since the Green revolution of 1960s, India has never looked back. It is also here pertinent to mention that the country's undernourished population decreased from 247.8 million in 2004-2006 to 224.3 million in 2019–21, according to a report from the State of Food Security and Nutrition in the World in 2022.

The horticulture production in the country has exceeded food grains production. The country has the largest area under cultivation. It is now the largest producer of pulses, spices, milk, tea, cashew, jute, banana, jackfruit and many other commodities (FAO). It stands second in production of fruits and vegetables, wheat, rice, cotton and oilseeds. India has the largest cotton cultivation area all over the world after China and the USA and it is the prime agriculture commodity or fiber crop worldwide. India is the third highest potato producing country and the second largest producer of Pulses in the world. The country also has the largest livestock population.

Despite remarkable achievements in the agriculture sector, there has been another side of this achievement. We have not yet been self sufficient in Pulses and Oilseeds. The negative impact and threat posed to our environment by climate change and large scale indiscriminate use of chemical fertilizers and plant protection chemicals to increase the yields are now clearly visible. The ground water has been rendered poisonous and contaminated with harmful chemicals. Such is the infestation that vast stretches of land extending up to kilometers is now not fit for any drinking water. Soils have been degraded, turned barren and a large number of biodiversity has been lost. Biodiversity is on the decline. Yields of crops are not increasing and large scale nutritional insecurity is manifested through children, pregnant and lactating mothers and adolescent girls.

The sector needs to embrace technologies which do not interfere with the environment, practices which are sustainable, and farming techniques like diversification and Integrated Farming System Models. At the same time it is also necessary that high value crops be promoted. Although we have attained food security for all, by nutritional security is a concern for all of us. To address nutritional security, a host of initiatives have been started. Biofortification and climate resilient varieties are being developed. From a chemical intensive green revolution, we have now to move towards an evergreen revolution based on the principles of natural farming, sustainability, local resource use efficiency, economic viability, social compatibility and profitability. Natural Farming is being promoted all across the country as environmental friendly approach. In the next two years one crore farmers would be roped in to practice natural farming. The food processing in the country is at present very low. The food processing sector can be utilized to enhance income opportunities for the rural population, facilitate job creation, minimize food wastage, improve the availability of nutritious foods by enhancing the processing of fruits and vegetables, and augment the proportion of value-added products.

The government of India has also come up with many pro-farmer schemes and programmes which include Primeminister Kisan Samman Nidhi (PMKISAN), Primeminister Krishi Sinchai Yojana (PMKSY), Soil Health Card (SHC), Primeminister Fasal Bima Yojana (PMFBY), and Primeminister Kisan Mandhan Yojana. To attract and retain Youth in agriculture, Entrepreneurship development schemes like Agri-Startups and skill development are being promoted with handholding and financial support to the youth who are interested in setting up agriculture or allied ventures. All these programmes have started showing results. Many youths have left their high earning jobs and started their own startups in agriculture and creating job opportunities for others also. Farmers particularly farm women feel more empowered, youths are now more skilled and the once static farming community is now a dynamic and vibrant one with collective approaches like Farmer Producer Organizations (FPOs).

The country has now set the goal of being a Developed Nation i. e *Viksit Bharat* by 2047. By 2047, India aims to become a developed nation. A recent article of Hon'ble Minister of Agriculture and Farmers' Welfare, GoI reported that for India to become a developed nation by 2047, its economy must grow at 7.8% annually with a projected population of 1.6 billion and half of that will be in urban areas. This shift will double overall food demand with demand for fruits, vegetables and animal based products expected to triple, while cereal demand remains stable leading to surpluses. However rising urbanization and industrialisation will shrink agricultural land from 180 million hectares to 176 million hectares and average land holdings from one hectare to 0.6 ha. This will further pressure on water and agro-chemicals risking resource degradation. The climate crisis poses an even greater threat endangering sustainable agriculture. India can expand pulses and oilseeds cultivation on 12 million hectare of rice-fallow land left unused due to various constraints. However, low yields of 18-40% gaps in oilseeds and 31-37% in pulses highlight the need for technological advancement.

Viksit Bharat is a vision for India to become a developed nation focusing on economic growth, social inclusion and environmental sustainability. The goal of *Viksit Bharat* is impossible to attain without giving due importance to agriculture. Agriculture is critical for India's development as it still engages about 45.8% of working population. If the dream of *Viksit Bharat* has to be realized and fulfilled by 2047, agriculture sector has to be developed to its full potential.

The author writes on agriculture and social issues; can be reached at *pkumar6674@gmail.com*

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Why Species Change: The Modern Tale of Natural Selection

Senthilkumar V.[1], Priya Garkoti[2], Anu Singh [3], Anamika Thakur [3] and Mayank

[1]Junior Research Fellow, ICAR - VPKAS, Almora, Uttarakhand.
[2]Ph. D. Research Scholar, GBPUAT, Pantnagar, Uttarakhand.
[3]Young Professional -II, ICAR - VPKAS, Almora, Uttarakhand.

Introduction

Darwin's theory of natural selection was accepted. The strong supporters of Darwinism are Wallace, Huxley, Haeckel, and Weismann. Darwin's theory lacked an input of modern concepts of genetics and the mechanisms how characters appear and persist in a population. In the light of recent researches, the theory was modified. Several experimental evidences have gone in favor of Darwinism. Based on those facts and statistical data a synthetic theory of evolution was proposed. This is modified theory of Darwinism. This is called Neo-Darwinism.

The Synthetic theory emerged by the synthesis of the original idea given by Charles Darwin and addition of new knowledge of genetics, population dynamics, statistics, and heredity to the theory. This is the most modern theory of evolution and has been constantly improved during 20th century by the contribution of the following scientists such as R.A. Fischer, J.B.S. Haldane, Ernst Mayr, Julian Huxley, and G.G. Simpson contributed with their studies on population dynamics. T. Dobzhansky, H.J. Muller, H. DeVries, G.L. Stebbins added information on genetics and mutation. G.H. Hardy, W. Weinberg, Sewall Wright did extensive work on population genetics and statistics, which helped to understand the mechanism of heredity.

According to Neo-Darwinism the following factors operate for the formation of new species.

a) Variations
b) Mutations
c) Natural selection
d) Genetic drift
e) Isolation of species.

Over production, struggle for existence, and universal occurrence of variation will take place as usual. But in the synthetic theory the formation of variations and mutations were discussed with experimental evidence for evolution which Darwin was unable to explain.

a) Variations: During Darwin's time little was known about genetic variations. During Meiosis and crossing over synapsis will take place. Because of this regrouping of genes will take place. Because of which genetic variation will appear or chromosomal aberrations will take place. The chromosomes may lose a bit or gain in a bit or order may be changed, or chromosomal bits may be exchanged between two chromosomes. These aberrations will become heritable variations.

Now and then the sets of chromosomes will increase or decrease. This is called ploidy. Because of this polyploidy heritable variations will arise they will be carried to number of generations. This may result in the origin of new species.

b) Mutations: Any change in the nucleotide sequence of DNA and if one pair of nucleotides is replaced mutations will arise. These mutations are called point mutations. These are caused spontaneously in nature. They can also be brought by induction. Mustard gas, x-rays, gamma rays, electric shocks, temperature shocks etc. will bring mutations. These mutations are rare. They are sudden and heritable. They may be harmful or beneficial. Most of the mutant genes are recessive. They can be expressed only in homozygous state.

Because of these sudden mutations new species are formed. For evolution, variations and mutations will be the raw material.

c) Natural Selection: Natural selection includes aft forces both physical and biotic factors and determine how and in what direction an organism is to change. Natural selection has no favoritism. But it is obvious that the organisms which are suited for environmental conditions will survive over power in the force of competition. Because of this better survivors are retained in the nature.

d) Genetic Drift: In small inter breeding population heterozygous gene pairs will tend to become homozygous. Because of this, disadvantage characters may be expressed and those organisms will be weeded out. Such genetic drifts are not theoretical. They operate in small populations of Islands. This genetic drift will provide a way to determine the line of evolution.

a) Isolation: In Darwin's time nothing to known about isolation. Isolation is very important part in evolution. Usually, the organisms of a population will be segregated into several populations because of physiological or geographical Isolation.

Mutations large stretches of water may separate a population in the separated groups one group may change. Because of this new species will be developed. Thus, geographical isolation will bring evolution.

The effects of natural selection in different environments will give different species. Thus, the old Darwin's concept is re-organized with experimental proofs, New- Darwinism was proposed.

Examples of natural selection

1. **The industrial melanic moth**: Biston betularia, the industrial melanic moth, is a gray colored moth that perfectly camouflages on tree trunks covered with lichen in England and escapes predation by birds. With industrial revolution in England in the middle of 19th century, lichens on tree trunks got killed due to smoke belching out of factories. Tree trunks were now bare and dark and made the light gray moth prominent to the predatory birds. Now natural selection favoured dark coloured moths, which could camouflage on bare tree trunks. Since the moth has only one generation in a year, in less than 50 generations, the natural selection replaced gray population with black population.
2. **Resistance in mosquitoes and houseflies:** DDT was used extensively, sometimes by airplanes over large areas. Initially it killed 99% of mosquito population but at the same time put a lot of pressure on the surviving individuals to mutate. Mutant resistant strains survived DDT application and became the parents of the next generation. Natural selection preserved the resistant populations and eliminated the susceptible ones. This can be called an artificial selection by man, due to which today not only mosquito and housefly but also many agricultural pests have become resistant to most of the available insecticides.
3. **Liederberg's replica plating experiment**: Liederberg (1952) conducted experiment on Escherichia coli by exposing the susceptible strains to penicillin repeatedly. As the generation time of the bacterium is 20-30 minutes only, hundreds of generations could be cultured and exposed to penicillin within a short time. He found that mutations for resistance appeared instantly and quickly replaced the susceptible populations by natural selection.
4. **Fluctuation test experiment**: Salvador Luria & Max Delbruck (1943) cultured a population of E. coli in one flask along with bacteriophage viruses. He then cultured samples from the flask on agar plates and found similar growth on all agar plates. He found that in some flasks instant mutations had appeared for resistance against viruses while in others susceptible strains died out. This experiment proved that in populations exposed to environmental extremes, either the mutants appear or hidden recessive mutations express and get exposed to natural selection and save the population from the possible extinction.

Conclusion

Natural selection is a phenomenon that forces the species to keep improving generation after generation so that they remain in the fittest state to survive in a particular environment. Random genetic changes provide raw material that causes variations and gives natural selection a chance to operate.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

A COMPREHENSIVE DESCRIPTION ON THE STRUCTURE OF MONOCOT AND DICOT SEEDS

Masoom Ankit Patel

M.Sc. (Agriculture) in Seed Science and Technology
Hemvati Nandan Bahuguna Garhwal University, Srinagar (Garhwal), Uttarakhand, India

ABSTRACT

Flowering plants rely on seeds as the basic unit of their reproduction, and these seeds hold a plant embryo with an embryonic structure accompanied by a nutrient store with covering layers. The fundamental knowledge of the organization of a monocotyledonous (monocot) and dicotyledonous (dicot) seed is critical to plant science, agriculture, and seed technology. Although the general structures of both types of seeds are similar, there is a big difference between the number of cotyledons, how they carry nutrients, and their cover. These variations affect germination physiology and seed storage behaviour, and crop management practices. In this article, the authors describe structural differences observed in the seeds belonging to monocots compared to those of dicots, functional implications of these differences, and their agricultural implications as perceived in the field of traditional botany, as well as current seed science. Rapid modernization of the seed sector and other innovations like the use of Artificial Intelligence (AI) in testing and certification of seed quality are improving our capacity to know and describe seed structures correctly, and therefore, such knowledge is becoming more useful towards sustainable crop production.

INTRODUCTION

The seeds connect two stages of the life cycle of a plant, namely the mature sporophyte and the embryonic. Seeds are the source of crop productivity in agriculture, and their quality as well as structural integrity determine the success of germination, seedling vigour, and yield potential. Department of Agriculture, Cooperation and Farmers Welfare (DACFW, 2020) states that quality seeds are capable of increasing crop yields by 20-25% and when quality seeds are subjected to good agronomic methods, the yields can increase by up to 40-45%. Broadly, angiosperm seeds are classified into:

- Monocotyledonous (monocot) seeds – having one cotyledon
- Dicotyledonous (dicot) seeds – having two cotyledons

Though the major seed parts are rather similar, any disparities in their inner structure bear biological and agricultural importance (Bewley *et al.*, 2013).

BASIC STRUCTURE OF A SEED

Before examining monocot-dicot differences, it is important to understand the basic seed components:

a. **Seed coat**: It is the outer layer that protects the seed and the embryo in the seed against mechanical and pathogenic injuries, and environmental stress. It is usually made up of two clearly distinct layers: the Testa, which is placed on the outer surface forming the outer coat, and the Tegmen, which is made up of a thinner, more delicate inner layer.

b. **Embryo:** It is the young plant that comprises the Radicle and Plumule, which eventually come up as roots and shoots, respectively.

c. **Cotyledon(s):** They are the leaves found in the seed to store or transmit food.

d. **Endosperm:** It is a reserve of nutrients, which may be starch, proteins, or lipids.

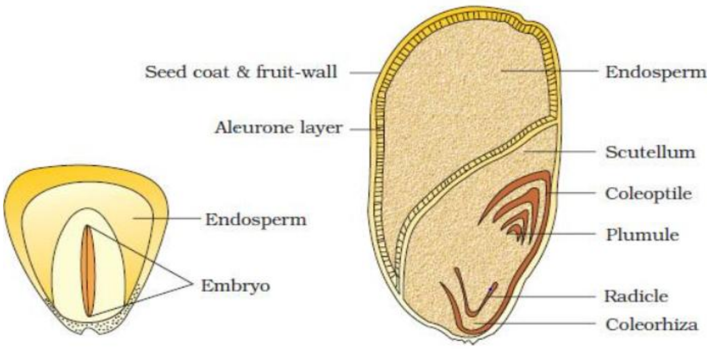
e. **Hilum and Micropyle:** These are the seed-attaching and water-entry points markings.

f. **Perisperm:** In other seeds, any leftovers of the nucellus function as foodstuff store called perisperm (Esau, 1977).

STRUCTURE AND SPECIAL FEATURES OF MONOCOT SEEDS

The most common examples of monocots are cereal grains such as Maize (*Zea mays*), Wheat (*Triticum aestivum*), and Rice (*Oryza sativa*). The structure of a monocot seed comprises of:

1. **Seed Coat & Fruit Wall**: The seed coat is united with the wall of the ovary, thereby forming a structure known as a caryopsis in monocots (Copeland & McDonald, 2012).
2. **Single Cotyledon (Scutellum):** Monocots have a single and reduced cotyledon called the SCUTELLUM. It is a specialized absorptive organ and not a storage organ.
3. **Endosperm**: The major tissue that stores nutrients, which are found in abundance in starch and proteins.



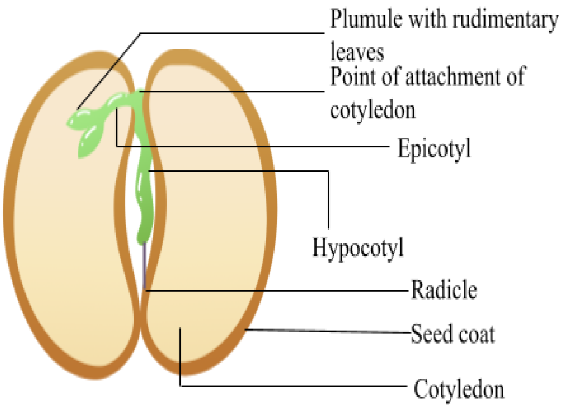
(Source: https://brainly.in/question/3274336)

4. **Aleurone Layer**: The outermost layer of endosperm includes cells and is rich in proteins, which play a role in releasing enzymes during germination.
5. **Scutellum**: It uptakes digested nutrients in the endosperm and transports them to the embryo.
6. **Coleoptile & coleorhiza**: These are anterior and are protective layers of the plumule and radicle, respectively. They both help in safe emergence during germination.
7. **Position of the Embryo**: Lateral
8. **Functional Implications:** On maturity, monocots have a larger endosperm. In this manner, the scutellum and protective sheaths enable monocots to grow in subjected soil conditions at seedling emergence (Bewley *et al.*, 2013).

STRUCTURE AND SPECIAL FEATURES OF DICOT SEEDS

The most common examples of dicots are Bean seed (*Phaseolus vulgaris*) or Pea (*Pisum sativum*). The structure of a dicot seed comprises of:

1. **Seed Coat**: It comprises a tough protective layer consisting of testa and tegmen.
2. **Hilum**: It is a scar marking the attachment point to the fruit wall.
3. **Micropyle**: It is a small pore for water entry during germination.
4. **Cotyledons**: Two cotyledons are present in dicot seeds. These serve as major food storage sites, rich in starch, proteins, and oils.
5. **Embryo Axis**: Situated between the cotyledons, it comprises the Radicle and Plumule, which later on develop into the root and shoot, respectively.

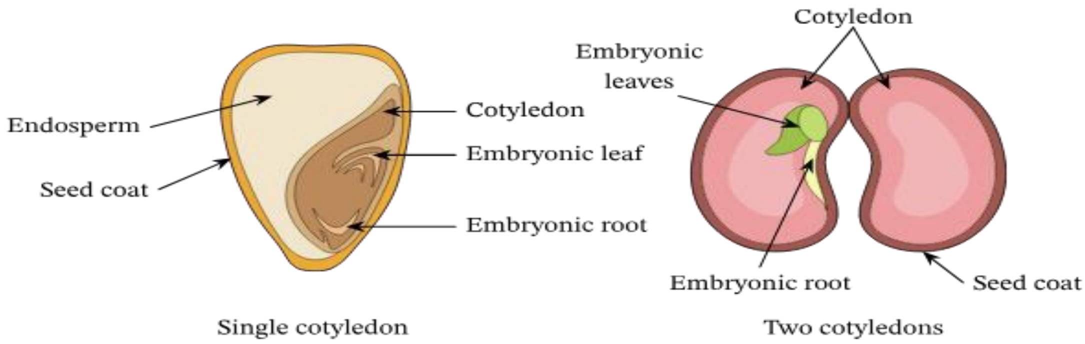


(Source: https://www.aakash.ac.in/important-concepts/biology/seed

6. **Endosperm**: It is usually absent at maturity in many dicots (e.g., beans) as nutrients are transferred to cotyledons during seed development. However, in some dicots (e.g., castor bean), endosperm persists (Esau, 1977).
7. **Functional Implications**: Cotyledons serve dual roles, like storage and first photosynthetic leaves after germination. The absence of endosperm in many dicots means germination relies directly on cotyledon reserves (Copeland & McDonald, 2012).

COMPARATIVE SUMMARY TABLE

Feature	**Monocot Seed**	**Dicot Seed**
Cotyledons	One (scutellum)	Two
Endosperm	Persistent at maturity	Often absent (non-endospermic)
Protective Sheaths	Coleoptile, coleorhiza	Absent
Embryo Position	Lateral	Central
Example	Maize, Wheat, Rice	Bean, Pea, Castor



(**Source**: https://www.nagwa.com/en/explainers/586108658402/)

SEED GERMINATION AND AGRICULTURAL RELEVANCE

Monocots August Monocots display germination that can be hypogeal (germination is below the soil surface), such as cereals whose cotyledon does not appear above the ground. Such a process of germination, along with intense protective processes, allows seeds to be sown both at multiple depths and in diverse soil textures (Bewley *et al.*, 2013). Comparatively, dicots are either epigeal or hypogeal in terms of germination, with the former characterizing placing the cotyledons above the ground or the latter based on the species. In the epigeal forms, the exposure of the cotyledons may also make the young seedlings more susceptible to environmental stresses (Esau, 1977).

IMPLICATIONS IN SEED TECHNOLOGY

Such knowledge about monocot and dicot seed structure contributes to:

- Identification of Seeds- This is valuable when determining purity in seed certification.
- Germination test- Knowing the sites of the nutrient reserves and their mobilization.
- AI-based Seed Quality Assessment- Modern applications such as machine learning and image recognition are able to discern structural characteristics (e.g., cotyledon number, seed coat integrity) fast and without errors (Patel, 2025).
- Ecological and Evolutionary Views- The monocotyledons have a single cotyledon and a fibrous root system, which tends to favour open grassland-like conditions. Dicot seeds with much more diverse means of storage strategy have a wider ecological niche (Bewley *et al.*, 2013).

CONCLUSION

Disparities in the structures of monocot and dicot seeds are not mere book definitions- they carry profound meaning regarding plant adaptation, seed technology, and farming. Such structures are important to know in the age of precision farming and the use of artificial intelligence in seed evaluation, adoption, and crop management to ensure accuracy and the maximization of productivity.

REFERENCES

Bewley, J. D., Bradford, K., & Hilhorst, H. (2012). Seeds: physiology of development, germination and dormancy. *Springer Science & Business Media.*

Copeland, L. O., & McDonald, M. F. (2012). Principles of seed science and technology. *Springer Science & Business Media.*

Department of Agriculture, Cooperation and Farmers Welfare (DACFW). (2020). *Annual report 2019–20.* Ministry of Agriculture & Farmers Welfare, Government of India.

Esau, K. (1977). Anatomy of seed plants, 2nd edn.(John Wiley and Sons: New York). NY, 445, 448.

Patel, M. A. (2025). The Role of Artificial Intelligence (AI) in Revolutionizing the Indian Seed Sector and Agricultural Transformation. *The Agriculture Magazine*, **04**(10), 146–150. https://doi.org/10.5281/zenodo.15817942

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Youth Participation in Agripreneurship: Challenges and Opportunities

Shardinjay Singh, Suchismita Sahoo, Rohan Kumar Singh, Swarima Singh, Sneha Singh

Department of Agricultural Extension Education, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, India

Introduction

The global agricultural sector stands at a critical juncture where the aging farming population and rural youth migration present significant challenges to food security and sustainable development. Youth participation in agripreneurship the intersection of agriculture and entrepreneurship has emerged as a crucial solution for addressing unemployment, food security, and rural development challenges across developing nations (Leavy & Hossain, 2014). Agripreneurship represents a transformative approach that combines traditional agricultural practices with innovative business models, technology adoption, and value chain development to create economically viable enterprises (Donkor et al., 2021).

The urgency of engaging youth in agricultural entrepreneurship is underscored by demographic trends across developing countries, where approximately 300 million young people are expected to enter the labor force over the next 30 years, with 195 million residing in rural areas (International Youth Foundation, 2014). Despite agriculture's potential as a growth sector, young people increasingly perceive farming as an unattractive career option due to various structural, social, and economic barriers. This paper examines the multifaceted challenges constraining youth participation in agripreneurship while identifying opportunities and policy interventions that can facilitate meaningful engagement of young entrepreneurs in agricultural value chains.

Keyword:- Agripreneurship, Youth Participation, Rural Development,Challenges,Opportunities

Conceptual Framework of Youth Agripreneurship

Agripreneurship encompasses a broad spectrum of entrepreneurial activities along agricultural value chains, from primary production and processing to marketing and service delivery. Unlike subsistence farming, agripreneurship emphasizes innovation, market orientation, risk management, and value addition as core principles for sustainable business development (Ansah et al., 2021). For youth, agripreneurship represents an opportunity to leverage their technological fluency, innovative mindset, and entrepreneurial energy to transform traditional agricultural systems while creating employment and income opportunities.

The concept of youth agripreneurship extends beyond farm production to include diverse activities such as agricultural input supply, equipment services, processing and value addition, marketing and distribution, agricultural advisory services, and agritourism development (Leavy & Hossain, 2014). This broad conceptualization enables young entrepreneurs to identify niche opportunities that align with their skills, interests, and available resources while contributing to agricultural sector modernization and rural economic development.

Barriers to Youth Participation in Agripreneurship

Financial and Capital Constraints

Access to finance remains the most significant barrier limiting youth engagement in agripreneurship across developing countries. Young entrepreneurs typically lack collateral, credit history, and financial literacy necessary to access formal credit markets (Donkor et al., 2021). Traditional financial institutions often perceive agricultural investments as high-risk ventures with uncertain returns, further restricting youth access to startup capital. In Zambia and Vietnam, studies indicate that lack of startup capital was identified as the primary barrier to effective youth engagement in agribusiness, with many young entrepreneurs relying on limited family savings and informal lending sources (Donkor et al., 2021).

The high initial investment requirements for agricultural enterprises, including land acquisition, equipment purchase, and working capital, create substantial entry barriers for resource-constrained youth. In Sweden, young agricultural entrepreneurs identified financial challenges with banks as the most significant barrier to overcome, though successful entrepreneurs demonstrated ability to develop innovative strategies and risk management approaches to address these constraints (Andersson & Eke-Göransson, 2024).

Land Access and Tenure Security

Land represents the fundamental production factor in agriculture, yet youth face significant challenges in accessing adequate and secure land tenure for agricultural ventures. In many developing countries, customary land tenure systems favor older generations, while formal land markets remain prohibitively expensive for young entrepreneurs (Leavy & Hossain, 2014). Limited land availability, high prices, and the impact of agricultural policies on land markets create additional barriers for new entrants seeking to establish viable agricultural enterprises.

The generational transfer of agricultural land often fails to provide adequate opportunities for youth participation, with many older farmers reluctant to transfer management control to younger family members. This phenomenon contributes to the aging of the agricultural workforce while limiting opportunities for innovation and modernization that young entrepreneurs could bring to farm operations (World Farmers' Organization, 2022).

Skills and Knowledge Gaps

Despite their technological fluency and innovative potential, many rural youth lack the specialized technical and business skills required for successful agripreneurship. Educational systems in developing countries often emphasize theoretical knowledge over practical entrepreneurial skills, creating a mismatch between youth capabilities and agribusiness requirements (Jayasudha & Muruganandam, 2020). Technical knowledge gaps include crop production techniques, livestock management, post-harvest handling, quality control, and integrated pest management practices.

Business management skills represent another critical constraint, with many young entrepreneurs lacking competencies in financial planning, market analysis, supply chain management, and strategic planning (Semkunde et al., 2022). The absence of entrepreneurship-focused agricultural education programs limits youth ability to develop comprehensive business plans and implement sustainable enterprise management practices.

Market Access and Value Chain Integration

Limited market access constrains youth participation in profitable agribusiness ventures, with many young entrepreneurs unable to establish reliable buyer relationships or access remunerative markets. The growing influence of supermarket chains and rigorous supply chain standards create additional barriers for small-scale youth enterprises that lack the volume, quality consistency, and certification required for formal market participation (Food and Agriculture Organization, 2018).

Information asymmetries regarding market prices, demand trends, and quality specifications limit youth ability to make informed production and marketing decisions. Young female entrepreneurs face additional constraints due to cultural norms that may restrict their mobility and market participation, further limiting their access to profitable opportunities along agricultural value chains.

Social and Cultural Barriers

Negative perceptions about agriculture as a backward, low-status occupation significantly influence youth attitudes toward agripreneurship. In many societies, parents actively discourage young people from pursuing agricultural careers, preferring white-collar professions perceived as offering higher social status and economic returns (Bezu & Holden, 2014). These negative perceptions contribute to rural-urban migration and reduce the pool of potential young agricultural entrepreneurs.

Cultural and gender norms may also restrict youth participation in agripreneurship, particularly for young women who face additional constraints related to land access, financial services, and market participation. Traditional role expectations and limited mobility can prevent young women from fully engaging in entrepreneurial activities along agricultural value chains.

Opportunities for Youth Engagement in Agripreneurship

Technological Innovation and Digital Agriculture

The rapid advancement of digital technologies presents unprecedented opportunities for youth engagement in agricultural entrepreneurship. Young people's familiarity with information and communication technologies positions them advantageously to adopt and develop digital solutions for agricultural challenges (Food and Agriculture Organization, 2023). Digital agriculture platforms enable precision farming, real-time monitoring, automated systems, and data-driven decisionmaking that can significantly improve agricultural productivity and profitability.

Mobile technology adoption creates opportunities for youth to develop innovative service delivery models, including agricultural advisory services, input supply platforms, market linkage systems, and financial service provision. In Rwanda, digital agriculture initiatives have demonstrated potential for enhancing youth engagement in agripreneurship through improved access to information, markets, and financial services (Food and Agriculture Organization, 2023).

Value Chain Diversification and Niche Markets

Modern agricultural value chains offer diverse entry points for youth entrepreneurs beyond traditional primary production. Processing and value addition activities provide opportunities to capture higher value margins while reducing dependence on volatile commodity prices. Young entrepreneurs can leverage their innovation capacity to develop new products, improve processing technologies, and create branded agricultural products for niche markets.

Specialty markets including organic agriculture, agritourism, direct marketing, and sustainable production systems offer opportunities for differentiation and premium pricing that can improve enterprise profitability. These niche markets often have less restrictive entry requirements and provide opportunities for young entrepreneurs to build market presence gradually while developing business capabilities.

Climate-Smart Agriculture and Sustainability

Growing emphasis on sustainable agriculture and climate change adaptation creates opportunities for youth entrepreneurs to develop innovative solutions for environmental challenges. Young entrepreneurs can pioneer adoption of climate-smart agricultural practices, renewable energy systems, water conservation technologies, and sustainable production methods that address both environmental concerns and market demands for sustainable products.

Carbon credit markets, environmental certification programs, and sustainability-focused value chains provide additional revenue opportunities for youth enterprises that adopt environmentally friendly practices. The alignment between youth environmental consciousness and market demand for sustainable products creates favorable conditions for youth engagement in climate-smart agripreneurship.

Supportive Policy Environment and Institutional Support

Recognition of youth employment challenges has prompted development of supportive policy frameworks and institutional mechanisms to facilitate youth entrepreneurship. Government programs providing startup grants, technical assistance, and preferential financing for young farmers create enabling conditions for agripreneurship development (World Farmers' Organization, 2022).

The European Union's young farmer payment scheme and startup aid programs demonstrate policy approaches that can significantly enhance youth participation in agriculture.

Development organizations and private sector partnerships increasingly focus on youth agricultural entrepreneurship through capacity building programs, incubation support, and market linkage facilitation. These institutional support systems can help address multiple barriers simultaneously while providing comprehensive assistance for youth enterprise development.

Strategic Interventions for Enhancing Youth Participation

Integrated Capacity Building Approaches

Successful youth agripreneurship programs require holistic capacity building that addresses technical, business, and life skills development simultaneously. The Jeunes Agriculteurs project in Senegal demonstrated the effectiveness of integrated training programs that combined entrepreneurship skills, agricultural techniques, and life skills development, resulting in the creation of 172 businesses and over 200 jobs (International Youth Foundation, 2014).

Educational institutions should develop specialized agripreneurship curricula that integrate practical training, mentorship opportunities, and exposure to successful agricultural enterprises. Industry partnerships can provide practical learning opportunities while connecting youth with potential markets and business networks.

Innovative Financing Mechanisms

Addressing financial constraints requires development of innovative financing approaches tailored to youth agripreneurship needs. Value chain financing models, including contract farming arrangements, supplier credit systems, and buyer-guaranteed financing, can provide alternative access to capital while ensuring market outlets for youth enterprises (Donkor et al., 2021).

Microfinance institutions, development finance organizations, and impact investors can develop youth-specific financing products with appropriate terms, collateral requirements, and repayment schedules. Group lending approaches and social collateral systems can help mitigate risks while building youth access to formal financial services.

Technology and Digital Platform Development

Investment in digital infrastructure and technology platforms can significantly enhance youth participation in agripreneurship by reducing transaction costs, improving information access, and facilitating market connections. Mobile-based applications for agricultural advisory services, input procurement, and market linkage can address multiple constraints simultaneously while leveraging youth technological capabilities.

Digital platforms can also facilitate peer learning networks, mentorship programs, and knowledge sharing among young agricultural entrepreneurs. Blockchain technology and digital payment systems can improve transparency, reduce transaction costs, and facilitate access to formal financial services for youth enterprises.

Policy and Institutional Reforms

Governments should develop comprehensive youth agripreneurship policies that address land access, financing, education, and market development simultaneously. Land reform programs that facilitate youth access to agricultural land, either through lease arrangements, cooperative ownership, or graduated transfer programs, can address fundamental resource constraints.

Regulatory reforms that simplify business registration, reduce bureaucratic barriers, and provide tax incentives for youth enterprises can lower entry costs and encourage entrepreneurship. Trade policies that facilitate market access for small-scale enterprises and quality certification programs can help youth enterprises compete in formal markets.

Case Studies and Best Practices

Senegal's Jeunes Agriculteurs Program

The Jeunes Agriculteurs project in Senegal provides a compelling example of successful youth agripreneurship programming. Over 18 months, the program trained 320 young people in entrepreneurship, agriculture, and life skills, ultimately supporting the establishment of 172 businesses that created over 200 jobs. The program's success factors included holistic training approaches, value chain focus, financing support, and community engagement (International Youth Foundation, 2014).

Rwanda's Digital Agriculture Initiative

Rwanda's collaboration with development organizations to enhance digital skills and innovation capabilities among youth and women demonstrates the potential for technology-focused interventions. The program addresses digital skills gaps while promoting agripreneurship through improved access to information, markets, and financial services (Food and Agriculture Organization, 2023).

European Union Young Farmer Support

The EU's comprehensive young farmer support framework, including direct payments and startup grants, demonstrates the effectiveness of policy interventions in promoting generational renewal in agriculture. The program provides both immediate financial support and long-term business development assistance, with differentiated support based on location, farm size, and additional job creation (European Parliament, 2017).

Conclusion and Policy Recommendations

Youth participation in agripreneurship represents a critical pathway for addressing unemployment, food security, and rural development challenges while facilitating agricultural sector modernization. However, realizing this potential requires comprehensive interventions that address the multifaceted barriers constraining youth engagement while leveraging emerging opportunities in technology, market diversification, and policy support.

Successful youth agripreneurship development requires integrated approaches that combine capacity building, financial services, technology adoption, and policy reforms. Programs must recognize youth diversity and provide differentiated support based on education levels, resource access, and entrepreneurial aspirations. Gender-sensitive programming is essential to ensure equitable participation of young women in agripreneurship opportunities.

The digital transformation of agriculture presents unprecedented opportunities for youth engagement, but requires investment in digital infrastructure, skills development, and platform creation. Climate change and sustainability concerns create additional opportunities for youth innovation in developing environmentally friendly agricultural solutions.

Policy makers should prioritize development of comprehensive youth agripreneurship strategies that address land access, financing, education, and market development simultaneously. International cooperation and knowledge sharing can facilitate adaptation of successful approaches across different contexts while building global networks of young agricultural entrepreneurs.

The success of youth agripreneurship initiatives ultimately depends on creating enabling environments that recognize young people as partners in agricultural transformation rather than passive beneficiaries of development interventions. By addressing structural barriers while leveraging youth innovations and energy, agripreneurship can contribute significantly to sustainable development goals while creating meaningful livelihood opportunities for the next generation of agricultural leaders.

References

Andersson, B., & Eke-Göransson, F. (2024). Entry Barriers for you agricultural entrepreneurs.

Mulema, J., Mugambi, I., Kansiime, M., Chan, H. T., Chimalizeni, M., Pham, T. X., & Oduor, G. (2021). Barriers and opportunities for the youth engagement in agribusiness: empirical evidence from Zambia and Vietnam. Development in Practice, 31(5), 690-706.

Bezu, S., & Holden, S. (2014). Are rural youth in Ethiopia abandoning agriculture?. World Development, 64, 259-272

Addo, P., Djekic-Ivankovic, M., Abdu, A., Boadi, P., Eyo, O., Baguignan, M. Y., ... & Marquis, G. S. (2024). Gender Role in Food Rights and Sovereignty in West Africa: A Rapid Review. African Journal of Food, Agriculture, Nutrition and Development, 24(10), 24725-24773.

Zagata, L., Hrabák, J., Lošťák, M., Bavorová, M., Ratinger, T., Sutherland, L. A., & McKee, A. (2017). Young Farmers: Policy Implementation After the 2013 CAP Reform.

Mungai, C., Muchaba, T., Szilagyi, L., Radeny, M. A., Atakos, V., & Ntiokam, D. (2018). Youth engagement in climate-smart agriculture in Africa: Opportunities and challenges.

Fiedler, Y. (2020). Empowering young agri-entrepreneurs to invest in agriculture and food systems (Doctoral dissertation, Food and Agriculture Organization of the United Nations).

Jayasudha J, RM Naik, KL Chaudhary. Barriers in agripreneurship experienced by the agricultural students in SAU's of Gujarat. Int J Agric Extension Social Dev 2024;7(4):134-137. DOI: 10.33545/26180723.2024.v7.i4b.510

Leavy, J., & Hossain, N. (2014). Who wants to farm? Youth aspirations, opportunities and rising food prices. IDS Working Papers, 2014(439), 1-44.

Ramesh Chandra Nautiyal, VLV Kameswari. Barriers to entrepreneurship among rural youth: Analyzing constraints in venture creation. Int J Agric Extension Social Dev 2025;8(1):167-169. DOI: 10.33545/26180723.2025.v8.i1c.1519

Manalili, N. M., & Capiña, X. G. B. (2023). Thailand's Young Smart Farmer (YSF) Program. Laguna, Philippines: Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA).

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

CROPWAT: A Smart Tool for Efficient Irrigation and Water Management

Abhishek Datir[1], Vaibhav Malunjkar[2] and Shubham Supekar[3]

[1]Research Associate, MPKV, Rahuri, Ahilyanagr, Maharashtra
[2] Research Associate, MPKV, Rahuri, Ahilyanagr, Maharashtra
[3]Senior Research Fellow, MPKV, Rahuri, Ahilyanagr, Maharashtra

Abstract

CROPWAT, developed by the Food and Agriculture Organization (FAO), is a widely used decision-support software designed to estimate crop water requirements and develop efficient irrigation schedules. The software utilizes climatic, soil, and crop data, combined with the FAO Penman–Monteith method, to calculate reference and crop evapotranspiration, net and gross irrigation requirements, and soil-water balances. Its user-friendly interface and integration with the CLIMWAT climate database make it accessible for both researchers and practitioners in diverse agro-ecological regions. Studies across India and beyond demonstrate its effectiveness in optimizing irrigation for crops such as rice, maize, lentil, tomato, and field pea, leading to significant water savings and yield improvements. While highly valuable for planning and policy-making, CROPWAT requires accurate input data and does not provide real-time irrigation automation. Overall, CROPWAT remains a crucial tool for promoting sustainable water management in agriculture.

Keywords: CROPWAT, FAO, Irrigation Scheduling, evapotranspiration

What is CROPWAT?

CROPWAT is a decision-support software developed by the Food and Agriculture Organization (FAO) of the United Nations. The current version, **CROPWAT 8.0**, runs on Windows and enables calculation of:

- Crop water requirements (ET_o and ETc)
- Net and gross irrigation needs
- Soil-water balance
- Custom irrigation schedules and scheme water supply planning up to 20 crops fao.orgfao.org

It incorporates climatic, soil and crop data, with defaults from the CLIMWAT database when local data aren't available fao.org.

How it Works

1. **Weather Data**: Using measured or CLIMWAT data, it applies FAO Penman–Monteith method to derive reference evapotranspiration (ET_o).
2. **Crop Parameters**: Crop coefficients and growth stages are used to estimate crop evapotranspiration (ETc).
3. **Soil-Water Balance Model**: On a daily or decadal basis, it calculates soil moisture dynamics to determine irrigation need.
4. **Scheduling**: You define management options, water application methods, and the software produces optimized irrigation calendars fao.orgfao.org.

Limitations and Considerations

- **Data-intensiveness**: Best results need accurate soil, climate, and crop info.
- **No Real-Time Field Automation**: Designed for planning, not direct control of irrigation systems.
- **Limited GIS Features**: Operates on a farm-by-farm or site-by-site basis, without map layers or spatial analytics.

Bringing It All Together

Adopting CROPWAT can transform irrigation from guesswork to data-driven scheduling. Success builds on:

- Gathering local climate, soil, and crop data
- Adjusting for crop growth stages
- Regular updating of schedules as conditions change

- Integrating with modern tools (e.g. sensor data, remote sensing) where possible

Quick Summary Table

Benefit	**Description**
Precision Irrigation	Reduces over- or under-watering
Water savings	Early sowing and optimal timing preserve resources
Yield support	Increases crop performance under stress or deficit
Flexible inputs	Works globally via CLIMWAT if local data missing
Planning-focused	Great for season/field-level strategy (not real-time)

References

- FAO documentation on CROPWAT 8.0 features and theory fao.orgfao.org
- Field studies: Lentil in Andhra Pradesh journal.jsure.org.in; Rice in Karnataka ebook.icar.gov.in; Odisha cereals scheduling arccjournals.com; Tomato/HYDRUS in Kashmir journal.agrimetassociation.org; Field Pea in Kashmir journal.jsure.org.in
- Review of methods, limitations, and integrations for CROPWAT 8.0 (2025) journals.acspublisher.com

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Advanced Agricultural Technologies: Farming Through Internet of Things Implementation

Dr. S. Anandhi

Assistant Professor of Mathematics, Anbil Dharmalingam Agricultural College and Research Institute, Tamil Nadu Agricultural University, Tiruchirappalli-620 027

INTRODUCTION

The demand for precision in agricultural resource management has intensified as farmers seek enhanced economic returns, optimal input efficiency, and environmental stewardship. This paradigm shift is driving Indian agriculture from conventional methods toward precision-based farming systems. Digital transformation plays a pivotal role in this agricultural evolution.

Internet of Things (IoT) applications in agricultural systems have fundamentally transformed farming methodologies, enabling agricultural professionals to observe and control their operations with unprecedented efficiency [1, 2]. The massive datasets generated by IoT systems demand rapid processing capabilities, which can be effectively addressed through Artificial Intelligence (AI) algorithms that deliver superior efficiency and high-quality decision-making outcomes. Contemporary approaches including machine learning algorithms, computer vision systems, artificial neural networks, and natural language processing have significantly enhanced agricultural automation processes. Machine learning and neural network technologies represent the most extensively researched automation tools in global agricultural applications.

Practical implementations encompass AI-enabled unmanned aircraft for field assessment, IoT-based automatic irrigation systems, field-embedded sensors for monitoring temperature variations, soil nutrition levels, moisture parameters and atmospheric humidity, plus robotic solutions.

IoT integration in agriculture merges scientific principles with technological innovation to boost overall production effectiveness through several mechanisms:

- Enhanced monitoring and sensing capabilities for production elements, including resource utilization, plant development phases, livestock behavior patterns, and food processing operations
- Improved comprehension of specific agricultural environments, encompassing meteorological conditions, environmental parameters, and the emergence of pests, invasive plants, and plant diseases
- Advanced remote management of farming, processing, and organizational activities using automated actuators and robotic systems, including targeted pesticide and fertilizer applications, and autonomous weed management robots
- Enhanced food quality surveillance and supply chain transparency through remote monitoring of shipment locations and product conditions
- Elevated consumer consciousness regarding sustainability and health considerations through personalized nutrition solutions, wearable technology, and household applications

This technological overview presents a comprehensive examination of agricultural IoT applications to provide deeper understanding of its potential contributions to addressing these agricultural challenges.

DRONE TECHNOLOGY IN AGRICULTURE

Unmanned Aerial Vehicles (UAVs), more commonly known as drones, represent cutting-edge technologies with significant agricultural potential. These devices incorporate sophisticated navigation systems, Global Positioning System (GPS) capabilities, multiple sensor arrays, premium cameras, programmable control units, and autonomous operational tools. Primary agricultural applications include terrain mapping, chemical and nutrient distribution, crop performance assessment, drone-based data analytics, and seeding operations. Drones can be configured with specialized equipment and sensors for resource mapping activities, such as crop species identification, cultivation area measurement, evaluation of environmental and biological stress factors, crop damage evaluation, nutrient deficiency detection, and soil moisture analysis. Drone technology is rapidly replacing traditional farming approaches and demonstrates extensive agricultural applications.

Agricultural Mapping and Irrigation Management: Drone technology has emerged as a revolutionary force in agricultural operations, providing multiple applications to enhance operational efficiency and productivity. Within Indian agricultural contexts, a critical application involves Agricultural Land Mapping. Drones equipped with high-definition cameras and sophisticated sensors enable comprehensive agricultural land mapping. This technology supports precise land utilization planning, identification of primary crop varieties, evaluation of land degradation, and management of soil physical and chemical characteristics. Furthermore, mapping provides essential insights into topographical features, supporting agricultural planning and agro-ecological classification. Through drone-based Agricultural Land Mapping, farmers obtain crucial information for informed decision-making and resource optimization.

Drones fitted with hyperspectral, thermal, or multispectral sensing equipment identify regions requiring moisture management or improvement interventions. Drone surveys enhance water utilization efficiency and reveal potential water accumulation or irrigation system leaks by providing monitoring capabilities that calculate vegetation indices to assess crop health and thermal energy emissions.

Plant Health Monitoring, Surveillance, and Fertilizer Distribution: Vegetation health monitoring and early detection of bacterial or fungal infections is essential for successful farming. Agricultural drones can identify plants that reflect different quantities of green and Near-infrared spectroscopy (NIRS) radiation. This data generates multispectral imagery for crop health monitoring. Rapid monitoring and defect identification can preserve crop yields. During crop failure events, farmers can document damages for precise insurance claim submissions.

Drone technology is revolutionizing conventional farming methods, particularly in fertilizer application domains. Drones equipped with specialized spraying systems provide precise and efficient alternatives to traditional application methods. In Indian agricultural contexts where precision farming is becoming prominent, drones serve crucial roles in optimizing fertilizer utilization. Farmers benefit from targeted application based on data from soil moisture analysis, nutrient deficiency assessment, and pest infestation monitoring. This technology reduces overall fertilizer consumption, minimizes environmental impacts, and maximizes crop production. Understanding per-acre or hourly costs for drone-based fertilizer application services is essential for farmers making informed operational decisions.

Automated Seeding and Crop Loss Assessment: Drone technology expands its capabilities to automated seedling or sapling planting, providing innovative solutions for labor-intensive operations. Drones equipped with seeding mechanisms can efficiently cover extensive areas while ensuring uniform planting density. This application particularly benefits Indian agricultural landscapes where large-scale plantations are prevalent. Automated drone planting enhances process speed and accuracy, contributing to increased efficiency and reduced manual labor requirements. Farmers gain access to cost-effective and time-saving crop establishment methods that further promote sustainable farming practices. Indian drone startups have developed planting systems enabling drones to deploy pods, seeds, and essential nutrients directly into soil. This technology reduces costs by approximately 85% while improving consistency and operational efficiency.

Agricultural Spraying Applications: Drone crop spraying reduces human exposure to harmful chemicals. Agricultural drones complete these tasks significantly faster than ground vehicles or aircraft. Drones equipped with RGB and multispectral sensors can identify and treat problematic areas specifically. Industry experts indicate that aerial drone spraying operates five times faster than alternative methods.

Agricultural drones with multispectral and RGB sensors detect field areas affected by weeds, infections, and pest infestations. This data determines precise chemical quantities needed to combat these problems, helping reduce farmer expenses.

Case Study: Locust Control Operations: Locust swarms commonly consume various plant species, including trees and agricultural crops. This feeding behavior can destroy cultivated crops in communities dependent on these food sources, resulting in food shortages and economic hardship. Locust swarms recently invaded multiple Indian regions, particularly Rajasthan. These expanding swarms threaten to become agricultural disasters, affecting approximately 90,000 hectares across 20 districts. Many nations rely heavily on organophosphate insecticides for locust control. These chemicals are applied through vehicle-mounted and aerial sprayers in concentrated, targeted amounts. Rajasthan has deployed drones to complete spraying operations efficiently.

Drone-based pesticide dispersal covers approximately 2.5 acres in 15 minutes. Drones provide rapid, safe, and practical methods for combating locust infestations.

Soil Mapping and Fertility Assessment: Drone surveys enable farmers to understand soil characteristics comprehensively. Multispectral sensors capture data applicable to seed planting patterns, detailed field soil analysis, irrigation management, and nitrogen level monitoring. Precise photogrammetry and 3D mapping technologies allow farmers to analyze soil properties extensively.

Drone integration in precision agriculture enables Soil Fertility and Field Assessment, providing farmers with critical land insights. Drones equipped with advanced sensors and imaging technology assess soil moisture levels, nutrient deficiencies, and overall soil health conditions. In Indian contexts where diverse soil types are common, this application helps farmers make informed decisions regarding crop selection and appropriate cultivation methods. Understanding per-acre charges for spectral and analytical services is essential for farmers seeking these services, ensuring optimal resource utilization and sustainable farming practices.

Wildlife Management and Livestock Monitoring: Drone technology serves as a versatile solution for addressing bird control challenges and human-animal conflicts in Indian agriculture. Drones equipped with deterrent systems, including sound or light devices, can be deployed above fields to protect crops from bird damage. Additionally, drones provide real-time surveillance capabilities, helping farmers monitor and manage potential wildlife conflicts. Timely drone interventions help minimize crop losses and promote coexistence between agricultural activities and wildlife.

Drone surveys also enable farmers to track livestock movements effectively. Thermal sensor technology assists in locating lost animals and detecting injuries or illnesses. Drones perform these functions efficiently, contributing significantly to agricultural productivity.

REMOTE SENSING IN AGRICULTURE

Remote sensing involves acquiring information about objects or phenomena from distant locations. This process utilizes instruments or sensors mounted on platforms such as satellites, aircraft, UAVs/UGVs, or probes. Sensors typically measure electromagnetic radiation either reflected or emitted by targets. IoT-based remote sensing employs sensors positioned at various farm locations where data is collected and transmitted to analytical tools for processing. These systems are sensitive to anomalies and collect data on soil moisture levels, temperature variations, and environmental factors, providing real-time crop health information. Farmers utilize this information to optimize farming practices for enhanced yields [3, 4].

Soil Temperature Monitoring: Accurate soil temperature measurement enables farmers to observe seasonal variations, identify optimal conditions for crop development, and adjust techniques accordingly. Soil temperature sensors provide continuous, instantaneous ground temperature monitoring, facilitating detection of subtle changes and patterns. Sensor wires or probes must be inserted into soil for temperature measurement. Sensing temperature ranges vary by sensor type. LM35 sensors operate within -55°C to 150°C ranges, though these sensors are expensive. Additional sensors collect humidity, moisture, precipitation, and dew detection data, helping determine farm weather patterns for appropriate cultivation timing.

Humidity Monitoring: These sensors detect, measure, and report relative air humidity or atmospheric water vapor content. Applications include greenhouse automation, hydroponic systems, plant transpiration optimization, terrarium monitoring, and vertical farming environment management.

Soil Moisture Detection: Soil moisture sensors measure current soil moisture levels. Agricultural irrigation systems integrate these sensors for precise watering schedule management. These tools help farmers adjust irrigation levels for optimal crop growth.

Weather Station Sensors: Self-contained units are positioned throughout growing fields at multiple locations. These stations feature sensors appropriate for local crops and climate conditions. They measure and record various parameters including air and soil temperatures, precipitation, leaf moisture, chlorophyll levels, wind velocity, dew point temperatures, wind direction, humidity, solar radiation, and atmospheric pressure. Data is transmitted wirelessly to central data loggers at specified intervals. Weather stations are becoming popular across farms of all sizes due to portability and decreasing costs.

ROBOTICS IN AGRICULTURE

Agricultural robots, termed Agribots, are gaining recognition due to increasing demands and global labor shortages. In the United States alone, crop production decreased by $3.1 billion annually due to labor shortages. Agribot development has accelerated with sensor and AI technology advancements. We remain in early stages of agricultural robotics revolution, with most products in trial phases and research development modes [3, 5].

Weed Control and Chemical Application: Multi-functional intelligent machines utilize vision systems including color-based and gray-level vision systems for automatic weed removal while enabling flexible irrigation rates in modern agriculture. These systems allow weed elimination without damaging cultivated crops. Additionally, they provide controlled pesticide and herbicide application to fields.

Machine Navigation Systems: Farm tractors and heavy plowing equipment can operate automatically through GPS systems similar to remote-controlled devices operated with controllers. These machines demonstrate accuracy and self-adjust based on terrain conditions, making labor-intensive tasks more manageable. Their movements and progress can be monitored through smartphones. These systems feature automatic obstacle detection capabilities through IoT and machine learning advancements.

Harvesting Operations: Agribots are utilized for picking mature fruits and vegetables, addressing labor shortage problems and reducing time consumption. These machines combine image processing with robotic arms to determine fruit selection, thereby controlling quality standards. Due to high operational costs, crops receiving early agribot harvesting focus include orchard fruits like apples. Greenhouse harvesting applications also utilize these robots for high-value crops including tomatoes and strawberries. These robots operate in greenhouse environments to accurately determine crop stages and harvest at optimal times.

The agricultural sector is rapidly transforming into a critical industry heavily dependent on advanced control systems managing increasing agricultural system complexity. Every farmland area is vital for maximizing crop production. Therefore, sustainable IoT-based sensors and communication technologies are necessary, and Indian agricultural community futures should definitely depend on IoT Technology. Farmers will require comprehensive training or collaborations with external professionals to understand complete procedures, including objective setting, achieving balance between software and technology tools, and understanding fundamental principles of employing such technologies.

References:

1. Zhang, L., Dabipi, I. K., & Brown, W. L. (2023). Internet of Things and smart sensors in agriculture: Scopes and challenges. Journal of Agriculture and Food Research, 14, 100776.

2. Morchid, A., Alaoui, A. E., Hassouni, L., & Medromi, H. (2024). Applications of internet of things (IoT) and sensors technology to increase food security and agricultural sustainability: Benefits and challenges. Ain Shams Engineering Journal, 15(3), 102509.

3. Kumar, S., Singh, R., & Patel, M. (2024). Integrating artificial intelligence and Internet of Things (IoT) for enhanced crop monitoring and management in precision agriculture. Smart Agricultural Technology, 8, 100147.

4. Rahman, A., Thompson, J., & Chen, Y. (2023). Advancements in smart farming: A comprehensive review of IoT, wireless communication, sensors, and hardware for agricultural automation. Biosystems Engineering, 234, 123-145.

5. Liu, H., Anderson, P., & Garcia, M. (2024). UAS-based remote sensing for agricultural monitoring: Current status and perspectives. Computers and Electronics in Agriculture, 225, 109258.

6. Patel, R., Wilson, K., & Lee, S. (2024). Leveraging precision agriculture techniques using UAVs and emerging disruptive technologies. Smart Agricultural Technology, 7, 100317.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Plant Epigenetics and Stress Memory: Mechanisms and Implications for Crop Resilience

Chandrasekhar Bhoi

Assistant Professor (TE) in Botany
B.J.B. Autonomous College, Bhubaneswar, India

Abstract:

Plants, being immobile organisms, are continuously challenged by fluctuating environmental conditions such as drought, heat, salinity, and nutrient limitation. To cope with these stresses, they have developed sophisticated regulatory mechanisms that extend beyond genetic variation and involve epigenetic modifications. Epigenetics encompasses heritable and reversible changes in gene expression mediated through DNA methylation, histone modifications, and non-coding RNAs without altering the underlying DNA sequence. Recent research has revealed that plants are capable of "stress memory," a phenomenon in which prior exposure to stress leaves molecular imprints that prime the plant for faster and stronger responses upon subsequent encounters. Evidence from model plants such as *Arabidopsis thaliana* as well as crops including rice, maize, and wheat indicates that epigenetic memory enhances resilience to abiotic stresses, improves germination, and stabilizes yields under adverse conditions. Advances in sequencing technologies and genome-editing tools have deepened our understanding of the epigenome and enabled the possibility of targeted manipulation of stress-responsive loci. Harnessing epigenetic memory holds significant promise for sustainable agriculture, offering new strategies for breeding climate-resilient crops, reducing dependence on chemical inputs, and improving food security in the face of global climate change.

Introduction:

Plants, as sessile organisms, are constantly exposed to fluctuating environmental conditions including drought, salinity, heat waves, and nutrient deficiencies. Unlike animals, they cannot escape from unfavorable conditions, and therefore must rely on internal regulatory networks that enable rapid adaptation and survival (Zhu, 2016). These adaptations involve not only transcriptional and physiological adjustments but also heritable molecular mechanisms that extend beyond the primary DNA sequence. Such mechanisms fall under the realm of epigenetics, broadly defined as reversible and sometimes heritable modifications to chromatin architecture and gene expression that occur without changes in the nucleotide sequence (Kohler & Springer, 2017).

Recent studies have revealed that plants possess the remarkable ability to "remember" prior stress exposures through epigenetic modifications, a phenomenon often referred to as stress memory (Crisp et al., 2016). Stress memory enables plants to mount quicker and stronger responses when the same or similar stress recurs, thereby improving their chances of survival and reproduction. This adaptive capacity is facilitated through processes such as DNA methylation, histone modification, and regulation by non-coding RNAs, all of which act to fine-tune stress-responsive gene expression (Lämke & Bäurle, 2017).

Importantly, some epigenetic modifications induced during stress are not limited to the individual plant's lifespan. In certain cases, they are transmitted through gametes to the next generation, resulting in transgenerational epigenetic inheritance (He & Li, 2018). For instance, progeny of drought-stressed *Arabidopsis thaliana* and rice plants have been shown to display enhanced drought tolerance and altered developmental traits compared to progeny from unstressed parents (Iwasaki & Paszkowski, 2014; Zheng et al., 2013). Such findings suggest that epigenetic memory provides plants with a mechanism to precondition offspring for anticipated environmental challenges.

Understanding stress memory is particularly relevant in the context of climate change, which has intensified the frequency and severity of abiotic stresses worldwide (Lesk et al., 2016). Traditional breeding and genetic engineering approaches have made significant contributions to crop improvement, yet they are often time-consuming and limited in scope. Epigenetic mechanisms offer a complementary strategy for enhancing stress resilience by enabling rapid, reversible, and potentially heritable responses to environmental variability (Springer

& Schmitz, 2017). As a result, the exploration of plant epigenetics and stress memory is emerging as a critical frontier in sustainable agriculture and food security research.

Plant stress memory is primarily mediated through epigenetic modifications that regulate chromatin structure and gene activity without altering the DNA sequence. These modifications ensure that stress-responsive genes are activated or silenced in a dynamic and often heritable manner. Three major mechanisms contribute to this process: DNA methylation, histone modifications, and non-coding RNAs.

2.1 DNA Methylation

DNA methylation refers to the covalent addition of a methyl group to cytosine residues, usually in CG, CHG, or CHH sequence contexts (where H = A, T, or C). This modification generally leads to transcriptional repression by preventing transcription factor binding or by recruiting proteins that condense chromatin (Law & Jacobsen, 2010).

Stress conditions such as drought, heat, or salinity induce dynamic reprogramming of DNA methylation at stress-responsive loci. For instance, drought stress in *Arabidopsis thaliana* results in locus-specific hypomethylation, activating protective genes (Boyko et al., 2010). Similarly, rice exposed to drought exhibits genome-wide DNA methylation changes, some of which are inherited by progeny, contributing to transgenerational stress memory (Zheng et al., 2013).

Thus, DNA methylation functions as a molecular “switch” that fine-tunes the expression of genes necessary for stress tolerance and, in some cases, transfers adaptive advantages to subsequent generations.

2.2 Histone Modifications

Histones, the proteins around which DNA is wrapped, are subject to a wide range of post-translational modifications including acetylation, methylation, phosphorylation, and ubiquitination. These chemical changes regulate chromatin accessibility and therefore transcriptional activity (Bannister & Kouzarides, 2011).

- **Histone acetylation** generally promotes transcription by loosening chromatin structure, facilitating access of transcription machinery. For example, increased acetylation of histone H3 has been linked to the activation of drought-responsive genes in *Arabidopsis* (Kim et al., 2015).
- **Histone methylation** has context-dependent roles: H3K4me3 is typically associated with active transcription, while H3K27me3 correlates with gene repression (Liu et al., 2014).
- During stress, specific histone modifications accumulate at promoters of stress-inducible genes, forming a kind of **chromatin-based memory**. After stress recovery, some of these modifications persist, enabling faster gene reactivation upon subsequent stress exposure (Lämke & Bäurle, 2017).

These findings indicate that histone modifications act as epigenetic bookmarks, recording past environmental challenges for more efficient responses in the future.

2.3 Non-Coding RNAs

In addition to DNA and histone modifications, non-coding RNAs (ncRNAs) play a central role in plant stress memory. Small interfering RNAs (siRNAs) and microRNAs (miRNAs) guide RNA-directed DNA methylation (RdDM), which establishes or reinforces DNA methylation patterns at specific loci (Matzke & Mosher, 2014).

- **siRNAs** derived from transposable elements or stress-related genes target DNA methyltransferases to specific sequences, thereby silencing unwanted or harmful gene expression during stress.
- **miRNAs** regulate stress-responsive transcription factors at the post-transcriptional level. For example, miR398 is downregulated under oxidative stress, leading to increased expression of superoxide dismutase genes, enhancing stress tolerance (Sunkar et al., 2012).

NcRNAs thus provide a flexible and sequence-specific regulatory layer that integrates environmental signals into stable epigenetic modifications, ensuring precise activation or repression of stress pathways.

3. Evidence of Stress Memory in Plants

The concept of epigenetic stress memory is supported by a growing body of experimental evidence across model plants and crop species. Stress memory manifests at both the individual level (short-term memory) and the generational level (transgenerational inheritance). Moreover, stress priming has been recognized as a practical mechanism by which plants can anticipate and prepare for future challenges.

3.1 Short-Term Stress Memory

Short-term stress memory occurs within the lifespan of an individual plant, allowing it to respond more efficiently when re-exposed to the same or similar stress. For example, *Arabidopsis thaliana* exposed to a period of drought demonstrated faster stomatal closure and more efficient water-use upon subsequent drought cycles, a clear physiological manifestation of stress memory (Ding et al., 2012). Similarly, heat stress in *Arabidopsis* induces the accumulation of specific histone modifications (H3K4me3) at promoters of heat-shock genes, which persist after the initial stress has subsided, enabling a quicker and stronger response upon recurring heat exposure (Lamke et al., 2016).

These findings indicate that stress memory is not limited to transcriptional responses but also involves chromatin-level modifications that act as molecular bookmarks for future activation.

3.2 Transgenerational Memory

In some cases, stress-induced epigenetic changes extend beyond the individual plant and are inherited by progeny. This transgenerational memory has been documented in both model and crop plants.

- In *Arabidopsis*, progeny of plants exposed to salt stress exhibited enhanced tolerance and altered gene expression profiles, correlated with DNA methylation changes (Boyko et al., 2010).
- In rice, drought stress induced widespread reprogramming of DNA methylation patterns, many of which were stably transmitted to offspring, resulting in improved drought resilience and altered root architecture (Zheng et al., 2013).
- Maize exposed to low-temperature stress produced progeny with increased germination rates and tolerance to chilling stress, suggesting heritable chromatin modifications (Ou et al., 2012).

Such examples support the idea that plants can "precondition" their progeny by transmitting epigenetic information about environmental stresses, a mechanism that could be highly beneficial under unpredictable climate conditions.

3.3 Stress Priming

Stress priming refers to the phenomenon where a mild or sub-lethal stress exposure enhances plant performance under subsequent severe stress. Epigenetic modifications play a central role in this preparedness.

For instance, *Arabidopsis* plants subjected to mild drought displayed enhanced growth and survival under later severe drought conditions, mediated by persistent DNA methylation and histone acetylation at drought-responsive loci (Sani et al., 2013). Similarly, pathogen priming has been observed, where exposure to non-lethal doses of biotic stress led to enhanced systemic acquired resistance (SAR) in later generations (Conrath et al., 2015).

Stress priming, therefore, represents a form of epigenetic training, equipping plants with a faster and more efficient defense strategy against environmental fluctuations.

4. Experimental Approaches

Understanding and manipulating epigenetic stress memory in plants relies on advanced molecular and genomic tools. These techniques allow researchers to map, characterize, and edit epigenetic marks that underlie stress responses. The most widely used approaches include whole-genome bisulfite sequencing (WGBS), chromatin immunoprecipitation sequencing (ChIP-seq), small RNA sequencing, and CRISPR/dCas9-based epigenetic editing.

4.1 Whole-Genome Bisulfite Sequencing (WGBS)

WGBS is considered the "gold standard" for detecting DNA methylation at single-base resolution. This method involves treating DNA with sodium bisulfite, which converts unmethylated cytosines to uracil while leaving methylated cytosines unchanged. Subsequent sequencing reveals genome-wide methylation patterns (Cokus et al., 2008).

In plant stress studies, WGBS has been used to map methylation changes in crops such as rice under drought, where specific loci involved in stress tolerance showed stable methylation alterations that persisted into progeny (Zheng et al., 2013). This approach provides valuable insights into how DNA methylation reprograms gene expression during environmental challenges

4.2 Chromatin Immunoprecipitation Sequencing (ChIP-seq)

ChIP-seq is employed to study histone modifications and transcription factor binding. The method uses antibodies against modified histones or transcription factors to immunoprecipitate DNA-protein complexes, followed by sequencing of associated DNA fragments (Johnson et al., 2007).

In the context of stress memory, ChIP-seq has revealed enrichment of H3K4me3 (activation mark) and depletion of H3K27me3 (repression mark) at drought- or heat-inducible genes in *Arabidopsis* (Kim et al., 2015). Such data help identify chromatin states that act as epigenetic bookmarks, enabling rapid reactivation of stress-responsive genes.

4.3 Small RNA Sequencing

Small RNA sequencing (sRNA-seq) is critical for profiling microRNAs (miRNAs) and small interfering RNAs (siRNAs), which regulate stress responses and direct RNA-directed DNA methylation (RdDM) pathways (Matzke & Mosher, 2014).

For example, sRNA-seq revealed that drought stress alters miRNA profiles in rice, including downregulation of miR398, which leads to the upregulation of antioxidant defense genes (Zhou et al., 2010). Such findings illustrate the central role of ncRNAs in shaping stress-responsive epigenomes.

4.4 CRISPR/dCas9 Epigenetic Editing

The development of CRISPR-based tools has enabled targeted editing of the epigenome without altering DNA sequence. The dCas9 (deactivated Cas9) protein can be fused with epigenetic modifiers such as DNA methyltransferases, demethylases, or histone acetyltransferases to activate or repress specific loci (Hilton et al., 2015).

Although still at an early stage in plant research, CRISPR/dCas9-based epigenetic editing holds great promise for engineering stress-resilient crops. For instance, targeting dCas9-TET (a DNA demethylase) to stress-inducible promoters could unlock silenced tolerance genes without creating permanent genetic modifications, potentially easing regulatory concerns.

5. Agricultural Implications

The discovery that plants can retain and transmit stress memory through epigenetic mechanisms holds profound implications for agriculture. By leveraging these processes, it may be possible to enhance crop resilience to climate change, reduce dependence on agrochemicals, and develop innovative breeding strategies. Moreover, advances in synthetic epigenetics provide opportunities for precise manipulation of stress-responsive traits without permanent genetic modifications.

5.1 Climate Resilience

With climate change intensifying the frequency and severity of droughts, heatwaves, and soil salinity, epigenetic stress memory provides a promising strategy for developing climate-resilient crops. Plants that retain memory of past stress can mount quicker and stronger responses during subsequent exposures, leading to improved survival and productivity under extreme environments (Lämke & Bäurle, 2017). For example, rice lines exhibiting inherited drought-induced methylation patterns have shown enhanced root growth and yield stability under water-deficient conditions (Zheng et al., 2013). Such findings highlight the potential to exploit naturally occurring epigenetic adaptations for crop improvement.

5.2 Reduced Chemical Inputs

Epigenetically primed plants can reduce reliance on fertilizers, pesticides, and growth regulators by optimizing intrinsic defense and nutrient-use pathways. For instance, stress-primed *Arabidopsis* and tomato plants demonstrated stronger immune responses to pathogens without additional chemical treatments (Conrath et al., 2015). If applied at scale, such epigenetically enhanced crops could significantly lower agricultural inputs, thereby minimizing environmental pollution and cutting production costs for farmers.

5.3 Breeding Strategies

Traditional breeding largely focuses on genetic variation, but epigenetic variation also contributes to phenotypic diversity and stress adaptation. By incorporating epigenetic markers (e.g., DNA methylation patterns, histone modifications) into breeding programs, breeders can select for heritable stress-memory traits. Recent studies in maize and rice indicate that epigenetic changes can be stably transmitted across generations (Ou et al., 2012; Quadrana & Colot, 2016), suggesting their potential as complementary tools to conventional and molecular breeding. Importantly, this approach may accelerate the development of resilient cultivars without the long timelines required for genetic introgression.

5.4 Synthetic Epigenetics

Synthetic biology offers tools to engineer epigenetic states with unprecedented precision. Using CRISPR/dCas9 fused to epigenetic modifiers, it is now possible to selectively activate or silence stress-related genes without altering the DNA sequence (Hilton et al., 2015). This approach could generate stress-hardy crops that avoid the controversies surrounding transgenic modification, since no foreign DNA needs to be permanently integrated. Furthermore, synthetic epigenetics is reversible, providing a flexible framework to design crops that can adapt dynamically to shifting climates and agricultural needs.

6**. Conclusion and Future Perspectives**

Plants possess a remarkable ability to sense, respond to, and "remember" environmental stresses such as drought, heat, and salinity through epigenetic mechanisms. DNA methylation, histone modifications, and non-coding RNAs enable the regulation of stress-responsive genes without altering the underlying DNA sequence, forming a molecular memory that can persist within a plant's lifetime and, in some cases, across generations. This stress memory allows plants to mount faster and stronger responses upon re-exposure to similar stresses, a phenomenon known as stress priming, and provides a potential pathway for transgenerational adaptation. Advances in experimental approaches, including whole-genome bisulfite sequencing, ChIP-seq, small RNA profiling, and CRISPR/dCas9-based epigenetic editing, have revealed the underlying molecular mechanisms and offer tools to manipulate stress memory for crop improvement. Harnessing these epigenetic insights holds significant promise for agriculture, enabling the development of climate-resilient crops, reducing chemical inputs, and complementing conventional breeding strategies. Ultimately, integrating plant stress memory into crop management and breeding programs provides a sustainable approach to enhance food security under increasingly unpredictable environmental conditions.

References:

1. Bannister, A.J., & Kouzarides, T. (2011). Regulation of chromatin by histone modifications. *Cell Research*, 21(3), 381–395.
2. Boyko, A., Blevins, T., Yao, Y., Golubov, A., Bilichak, A., Ilnytskyy, Y., Hollunder, J., Meins, F., & Kovalchuk, I. (2010). Transgenerational adaptation of Arabidopsis to stress requires DNA methylation and the function of Dicer-like proteins. *PLoS ONE*, 5(3), e9514.
3. Conrath, U., Beckers, G.J.M., Langenbach, C.J.G., & Jaskiewicz, M.R. (2015). Priming for enhanced defense. *Annual Review of Phytopathology*, 53, 97–119.
4. Crisp, P.A., Ganguly, D., Eichten, S.R., Borevitz, J.O., & Pogson, B.J. (2016). Reconsidering plant memory: Intersections between stress recovery, RNA turnover, and epigenetics. *Science Advances*, 2(2), e1501340.
5. Ding, Y., Fromm, M., & Avramova, Z. (2012). Multiple exposures to drought 'train' transcriptional responses in Arabidopsis. *Nature Communications*, 3, 740.
6. He, G., & Li, J. (2018). Epigenetic environmental memories in plants: Establishment, maintenance, and reprogramming. *Trends in Genetics*, 34(11), 856–866.
7. Hilton, I.B., D'Ippolito, A.M., Vockley, C.M., Thakore, P.I., Crawford, G.E., Reddy, T.E., & Gersbach, C.A. (2015). Epigenome editing by a CRISPR–Cas9-based acetyltransferase activates genes from promoters and enhancers. *Nature Biotechnology*, 33(5), 510–517.
8. Iwasaki, M., & Paszkowski, J. (2014). Epigenetic memory in plants. *EMBO Journal*, 33(18), 1987–1998.
9. Kim, J.M., To, T.K., Ishida, J., Matsui, A., Kimura, H., & Seki, M. (2015). Transition of chromatin status during the process of recovery from drought stress in Arabidopsis thaliana. *Plant & Cell Physiology*, 53(5), 847–856.
10. Kohler, C., & Springer, N.M. (2017). Plant epigenomics: Decoding the mechanisms of epigenetic inheritance and plasticity. *Annual Review of Plant Biology*, 68, 263–288.
11. Lämke, J., & Bäurle, I. (2017). Epigenetic and chromatin-based mechanisms in environmental stress adaptation and stress memory in plants. *Genome Biology*, 18(1), 124

12. Lamke, J., Brzezinka, K., Altmann, S., & Bäurle, I. (2016). A hit-and-run heat shock factor governs sustained histone methylation and transcriptional stress memory. *EMBO Journal*, 35(2), 162–175.
13. Law, J.A., & Jacobsen, S.E. (2010). Establishing, maintaining and modifying DNA methylation patterns in plants and animals. *Nature Reviews Genetics*, 11(3), 204–220.
14. Lesk, C., Rowhani, P., & Ramankutty, N. (2016). Influence of extreme weather disasters on global crop production. *Nature*, 529(7584), 84–87.
15. Liu, C., Lu, F., Cui, X., & Cao, X. (2014). Histone methylation in higher plants. *Annual Review of Plant Biology*, 61, 395–420.
16. Matzke, M.A., & Mosher, R.A. (2014). RNA-directed DNA methylation: An epigenetic pathway of increasing complexity. *Nature Reviews Genetics*, 15(6), 394–408.
17. Ou, X., Zhang, Y., Xu, C., Lin, X., Zang, Q., Zhuang, T., Jiang, L., von Wettstein, D., & Liu, B. (2012). Transgenerational inheritance of modified DNA methylation patterns and enhanced tolerance induced by cold priming in maize. *Plant Molecular Biology*, 79, 467–479.
18. Quadrana, L., & Colot, V. (2016). Plant transgenerational epigenetics. *Annual Review of Genetics*, 50, 467–491.
19. Sani, E., Herzyk, P., Perrella, G., Colot, V., & Amtmann, A. (2013). Hyperosmotic priming of Arabidopsis thaliana seedlings establishes a long-term somatic memory accompanied by specific changes of the epigenome. *Genome Biology*, 14(6), R59.
20. Springer, N.M., & Schmitz, R.J. (2017). Exploiting induced and natural epigenetic variation for crop improvement. *Nature Reviews Genetics*, 18(9), 563–575.
21. Sunkar, R., Li, Y.F., & Jagadeeswaran, G. (2012). Functions of microRNAs in plant stress responses. *Trends in Plant Science*, 17(4), 196–203.
22. Zheng, X., Chen, L., Xia, H., Wei, H., Lou, Q., Li, M., Li, T., & Luo, L. (2013). Transgenerational epigenetic inheritance of genome-wide DNA methylation in rice under drought stress. *PLoS ONE*, 8(5), e64293.
23. Zhu, J.K. (2016). Abiotic stress signaling and responses in plants. *Cell*, 167(2), 313–324.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Organic Mulberry Cultivation: Prospects and Challenges

M. PARASURAMUDU, M. VENKATESH PRASAD, K. NANDHINI

Post graduate, Department of Sericulture, Sri Krishna Devaraya University, Anantapur-515003, Andhra Pradesh

Introduction

Mulberry (Morus spp.) cultivation forms the backbone of sericulture, as its leaves are the exclusive food source for the silkworm (*Bombyx mori* L.). Traditionally, farmers have relied heavily on chemical fertilizers, pesticides, and growth regulators to boost leaf yield and quality. However, the excessive use of such inputs has led to several environmental and economic problems, including soil degradation, pest resistance, water contamination, and health risks to farmers and consumers.

In recent years, the concept of organic farming has gained global attention as a sustainable approach to crop cultivation. Organic mulberry farming avoids synthetic agrochemicals and instead relies on eco-friendly practices such as composting, biofertilizers, crop rotation, mulching, and biological pest management. For sericulture, this transition is particularly important because the quality of mulberry leaves directly influences silkworm growth, cocoon formation, and raw silk production.

Thus, exploring the prospects and challenges of organic mulberry cultivation is essential for ensuring both environmental sustainability and economic viability in sericulture.

Prospects of Organic Mulberry Cultivation

1. Enhanced Soil Fertility and Leaf Quality

Soil health plays a fundamental role in sustainable mulberry cultivation and directly influences the quality of leaves, which are the sole food source for silkworms. The application of organic manures such as farmyard manure, compost, green manure, and vermicompost enriches the soil with essential macro- and micronutrients while also improving soil texture, aeration, and water-holding capacity. These organic amendments not only supply nutrients but also stimulate microbial activity, which contributes to long-term soil fertility.

In addition, the integration of biofertilizers such as *Azotobacter*, *Azospirillum*, and phosphate-solubilizing bacteria (PSB) further enhances nutrient availability in the rhizosphere by fixing atmospheric nitrogen and solubilizing bound phosphorus, thereby reducing dependence on chemical fertilizers. Similarly, the inoculation of mycorrhizal fungi improves root colonization, increases absorption of phosphorus, zinc, and other micronutrients, and strengthens plant resilience against biotic and abiotic stresses.

The synergistic effects of these soil-enriching practices ensure the production of nutritionally balanced mulberry leaves rich in proteins, vitamins, and minerals. High-quality leaves have a direct impact on silkworm rearing performance, leading to faster larval growth, increased cocoon weight, improved shell ratio, and longer and stronger silk filament length. Ultimately, soil fertility management through organics and biofertilizers contributes not only to sustainable sericulture but also to higher productivity and profitability for farmers.

2. Eco-Friendly and Sustainable Farming

Organic cultivation in mulberry farming emphasizes the use of natural inputs and eco-friendly practices, which significantly reduce dependence on synthetic fertilizers and chemical pesticides. By minimizing the application of agrochemicals, organic farming lowers the risk of soil degradation, water pollution, and toxic residues that may accumulate in the ecosystem. This creates a safer environment not only for crops but also for farm workers, silkworms, and end consumers of silk products.

Natural farming practices also contribute to the enhancement of soil biodiversity. The incorporation of organic matter improves soil organic carbon and creates favorable conditions for earthworms, beneficial microbes, and soil-dwelling insects. These organisms, in turn, facilitate nutrient cycling, improve soil porosity, and enhance the natural disease-suppressive ability of the soil. A biologically active soil ecosystem ensures long-term sustainability and resilience against pests and diseases, reducing the reliance on chemical control measures.

Moreover, organic sericulture aligns with global strategies to combat climate change. The reduced usage of chemical fertilizers significantly lowers greenhouse gas emissions associated with their industrial production and application. Practices such as composting, green manuring, and vermicomposting also contribute to carbon sequestration in soils, thus playing a dual role in improving soil fertility and mitigating climate change.

3. Employment and Rural Development

Organic sericulture plays a pivotal role in employment generation and rural development, particularly in regions where agriculture remains the primary livelihood. Unlike conventional farming, organic practices rely less on mechanization and more on human labor for activities such as compost preparation, manual weeding, mulching, vermicomposting, and the preparation and application of bio-pesticides**.** These labor-intensive operations create consistent employment opportunities for rural households throughout the year, thereby reducing migration to urban areas in search of work.

A notable social benefit of organic sericulture is its inclusiveness. Since the system is well-suited for small and marginal farmers, it allows families with limited landholdings to actively participate in silk production. Furthermore, women play a crucial role in various stages of organic farming and cocoon production, including leaf collection, silkworm rearing, and waste recycling. This enhances their economic independence and empowerment, contributing to improved household income and rural community stability.

Challenges of Organic Mulberry Cultivation

1. Pest and Disease Management

Mulberry, being a perennial crop, is highly vulnerable to a variety of pests and diseases that can drastically reduce both leaf yield and quality, thereby affecting cocoon productivity. Among the major pests, the **tukra (*Maconellicoccus hirsutus*)**, leaf rollers, and root-feeding pathogens are the most destructive. Leaf rollers damage tender foliage, limiting the availability of quality leaves for silkworm rearing. Similarly, root rot caused by soil-borne fungi weakens plants, leading to reduced leaf biomass and even plant mortality under severe cases.

In organic and sustainable sericulture systems, chemical pesticides are avoided, and farmers must instead depend on **ecologically safe pest management strategies**. These include the use of **biological control agents** such as predators and parasitoids that naturally regulate pest populations. Additionally, **botanical extracts** like neem oil or neem seed kernel extract are applied for their antifeedant and insecticidal properties

However, the effectiveness of these measures can vary depending on environmental conditions and pest load. Under **severe outbreaks**, biological and botanical methods may not act as quickly or effectively as synthetic chemicals, posing a challenge to farmers. This highlights the need for **integrated pest management (IPM)** strategies that combine cultural practices (e.g., pruning, sanitation, and crop rotation), biological control, resistant varieties, and judicious use of eco-friendly formulations.

Adopting such integrated approaches ensures **sustainable pest and disease management**, protecting mulberry crops while maintaining environmental safety and producing high-quality leaves for sericulture.

2. Lack of Awareness and Training

A significant constraint in the adoption of organic sericulture is the **limited awareness and technical knowledge** among farmers. Many small and marginal sericulturists are not familiar with the use of organic inputs such as biofertilizers, vermicompost, green manure, and microbial bio-pesticides. Similarly, essential practices like **compost preparation, nutrient recycling, and integrated organic pest and disease management** are either poorly understood or inadequately implemented.

In several sericulture-growing regions, **extension services and farmer training programs** remain insufficient. Existing programs are often irregular, geographically limited, or focused more on conventional practices than on organic methods. This gap restricts farmers from learning modern, eco-friendly approaches and accessing information about organic certification procedures, value addition, and premium market opportunities.

The lack of structured training also means that farmers are often unable to effectively handle challenges such as pest outbreaks, nutrient deficiencies, and soil health management under organic systems. Without adequate knowledge support, the shift from conventional to organic sericulture becomes difficult, leading to partial adoption or reversion to chemical practices.

Strengthening **capacity-building initiatives**, establishing **demonstration plots**, and providing **hands-on training workshops** tailored to local conditions are essential to bridge this gap. Involving women farmers and youth in such programs can further enhance community participation and ensure wider dissemination of knowledge. Ultimately, improving farmer awareness and technical skills will accelerate the successful adoption of organic sericulture and enhance its contribution to sustainable silk production.

Future Prospects and Research Opportunities

1. Development of Organic-Specific Mulberry Varieties

Future research must focus on breeding and developing **mulberry varieties suited to organic conditions**. These varieties should possess traits such as **pest and disease resistance, drought tolerance, and higher nutrient content** in leaves. Such characteristics will reduce dependency on external inputs, enhance resilience under low-input organic systems, and improve leaf quality for silkworm rearing. Genomic tools, molecular breeding, and participatory breeding with farmers can accelerate the development of such varieties.

2. Improved Bio-Inputs

Advances in **biofertilizers, microbial consortia, and botanical pesticides** are critical for strengthening nutrient and pest management in organic sericulture. Multi-strain microbial formulations that combine nitrogen-fixing, phosphate-solubilizing, and growth-promoting organisms can significantly enhance soil fertility. Similarly, innovations in **plant based-pesticides** e.g., neem, pongamia. Research on low-cost, farmer-friendly production technologies for these inputs will ensure wider adoption.

3. Policy and Government Support

The role of government policy is pivotal in scaling up organic sericulture. Measures such as providing subsidies for organic inputs, along with the inclusion of organic sericulture in rural development schemes, livelihood missions, and women empowerment programs, can expand participation and ensure social inclusiveness.

4. Integration with Sustainable Farming Models

Organic mulberry cultivation can be effectively integrated into **holistic farming systems** such as agroforestry, vermiculture, and livestock farming. Such integrated models improve **resource-use efficiency, recycling of organic waste, and diversification of income sources**. For example, livestock manure can be converted into vermicompost for mulberry fields, while mulberry pruning's can be used as fodder or fuel. This not only strengthens farm-level sustainability but also enhances resilience to climate change and market fluctuations.

Conclusion

Organic mulberry cultivation represents a **transformative approach** to sustainable sericulture, offering a viable alternative to the chemical-intensive practices that have long dominated the sector. By relying on organic manures, biofertilizers, and ecological pest management, this system not only improves **soil fertility, soil health, and biodiversity**, but also enhances the **nutritional quality of mulberry leaves**, resulting in healthier silkworms, superior cocoon quality, and premium-grade silk. In addition, organic sericulture reduces the environmental footprint of silk production, thereby aligning with global priorities for **climate change mitigation and eco-friendly agriculture**.

However, despite these clear benefits, the widespread adoption of organic mulberry farming faces notable constraints. Initial yields under organic conditions are often lower compared to conventional systems, particularly during the transition phase. Pest and disease outbreaks remain a serious concern, as natural control agents and botanical pesticides sometimes fail to provide the same level of protection as synthetic chemicals.

Looking forward, a **multi-pronged strategy** is required to realize the full potential of organic sericulture. Research must prioritize the development of **organic-specific mulberry varieties** that are pest-resistant, drought-tolerant, and rich in nutrients. Technological innovations in **biofertilizers, microbial consortia, and botanical pesticides** can significantly improve soil fertility and pest management efficiency under organic conditions. Stronger **government support**, including subsidies for organic inputs. Additionally, large-scale **capacity-building programs, farmer training, and extension services** are essential to enhance awareness and equip farmers with the necessary skills for organic cultivation practices.

Finally, the integration of organic mulberry cultivation with **sustainable farming models** such as agroforestry, vermiculture, and livestock farming can further improve resource-use efficiency and diversify farmer incomes. By combining scientific innovation, policy support, farmer empowerment, and robust market linkages, organic sericulture can evolve into a model of **sustainable rural development**. Ultimately, the shift toward organic practices will not only safeguard natural resources and ensure environmental sustainability but also secure the **long-term economic resilience** of sericulture farmers in the face of global environmental and market challenges.

Vermicompost Farming: The Black Gold for Your Farm

Dr. Niharika Shukla, Dr. Rashmi Shukla and Dr. Yati Raj Khare

Scientists

Krishi Vigyan Kendra, College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidhyala, Jabalpur

Introduction

Vermicomposting farming has been a revolutionary, eco-friendly form of farming referred to as "black gold" in agriculture. More farmers are discovering the benefits of earthworm compost and how to do vermicomposting. In this article, we reveal why vermicompost is so influential, share best practices, and demonstrate how it can bring life to your farm, ecologically and economically.

What Is Vermicomposting and Why Is It Black Gold?

Vermicomposting is the organic process by which earthworms, particularly red wigglers (*Eisenia fetida*), break down farm organic residues and plant crop wastes into a rich compost known as worm castings or vermicast. The castings are often referred to as "black gold" because they are highly concentrated with plant-accessible nutrients and microorganisms that significantly enhance soil fertility. This natural compost is one of the central roles of regenerative agriculture through increased soil health, improving microbial equilibrium, and reducing expenses while significantly improving crop yields. Its extremely high agronomic value makes it a central feature of vermicomposting farming, long-term soil fertility management.

Most Significant Benefits of Earthworm Compost

One of the most significant facts about how vermicomposting farming has gained so much popularity is that the earthworm compost is immensely beneficial. Not only does it improve aeration and water retaining capacity in the soil, but it also reduces the reliance on chemical inputs. Earthworm compost is rich in a very high content of plant nutrients and microbes that promote ecological stability of the land and promote sustainable development of the crop. Farmers should be well informed about earthworm compost advantages so that they can raise the yield without damaging their land.

1. Better Soil Structure & Fertility

Vermicompost increases the aeration, porosity, bulk density, and water-holding capacity of the soil, facilitating maximum root growth. Increased microbial activity in the soil intensifies nutrient cycling and plant hormones like auxins and gibberellic acid.

2. Natural Nutrient Reservoir

Earthworms convert nitrogen through legumes and recycle phosphorus and potassium from low soil, vermicomposting farming, hence an economical means of soil fertility organically.

3. Soil Health & Pest Resistance

Worm castings suppress disease pathogens, build microbial resistance, and decrease dependence on chemical inputs, providing sustenance for healthier plant populations with reduced pests and disease agents.

4. Environmental & Economic Sustainability

It minimizes waste going to landfills, reduces greenhouse gases, creates local employment, and entails minimum capital investment, making it perfect for small to large farms.

How to Do Vermicomposting Successfully on Your Farm

If you are researching vermicomposting, the wonderful thing is that it's a low-cost and flexible process for any farm size. From getting started with compost beds and the correct worm species to optimal temps and moisture, successful vermicomposting requires minimal infrastructure and lots of organic matter care. Getting the early vermicomposting farming techniques right allows farmers to turn waste into a resource for their soil improvement.

Choosing Your Worms & Bin Setup

Red wigglers (*Eisenia fetida*) or E. andrei are best for maximum vermicomposting. The bins should also be ventilated and have drainage holes, and should not contain antimicrobial woods such as cedar.

Bedding & Feedstock

Begin with damp, torn paper or cardboard bedding. Store worms in natural matter like vegetable waste, coffee grounds, and plant clippings. Don't overfeed with meat, milk, or citrus because it will cause a pH imbalance and pests.

Maintenance & Harvesting

Sustain 70–80% humidity and 15–30 °C room temperatures to ensure worm activity. Castings are collected using methods like pyramid sorting or container separation; worms and cocoons are cycled back to the bin for perpetuity.

Covering Different Methods

- Farmers can utilize different models to scale vermicomposting:
- Small farmer bins: plain plastic totes that contain many hundreds of worms.
- On-farm units: larger, modular systems for processing crop residues. Institutional/regenerative systems, including schools, municipalities, or agro-ecosystems.

Vermicomposting Farming vs Traditional Composting: What's the Difference?

Both processes, though based on the reuse of organic wastes, have some benefits of vermicomposting agriculture over normal composting. Composting is more effective, rapid, and yields compost with higher bioavailability of nutrients through earthworm biological action. Farmers can choose the appropriate process based on their sustainability targets and their agricultural practices by understanding the difference between vermicomposting and normal composting.

Key Earthworm Compost Benefits for Farms

- Increased crop yields and improved germination, due to improved soil biology.
- Lower fertilizer cost as micronutrients are easily bioavailable.
- Increased competitive barriers against weed cover and erosion by the improved cover and soil structure.
- Long-term stability through conserved microbial life and carbon sequestration by the soil

How to Identify Quality Earthworm Compost

Not all composts are equal. In agriculture using vermicomposting, good earthworm compost must be assessed based on color, odor, texture, and nutrient status. Ideal compost will have a dark color, crumb-like texture, no odor, and worm casts showing fine fragmentation. Farmers should be label-conscious and also watch out for adulteration or substandard input when buying compost from other sources. Having the ability to sample the quality of the compost means that your plants are getting the best out of earthworm compost.

Real-World Evidence & Further Reading

Soil treated with vermipost had better physical, chemical, and biological characteristics in a review study, which improved plant health and yield of crops, but should be utilized at moderate levels to prevent salt buildup.

Practical Use Cases & Applications

- Mixed farming systems: incorporate vermicompost into the soil before sowing cash crops.
- Seedling growth medium: utilise worm tea or diluted vermicast in nursery trays.
- Field amendments: cast broadcast at 5–10% field volume or as top-dressing.

Challenges and Considerations

- Steep learning curve initially: determination of appropriate worms, type of bin, and moisture control/pH.
- Seed cost and culture: purchasing quality worms until the economy of scale is reached at local farms.
- Maturation period: vermicomposting 2–3 months from start to complete maturity.

Future Outlook: Vermicomposting Farming as a Core Practice

As popularity builds for the regenerative agriculture movement, vermicomposting agriculture will be an indispensable practice in the near future for governments and farm communities everywhere, and in India, for the sake of stimulating organic composting business. The endorsement of initiatives and subsidy of Urban Worm Company.

Conclusion

Vermicomposting agriculture is a holistic, low-input, nature-based approach to soil fertility enhancement, ecological balance, and economic viability. Incorporating worm composting into agriculture allows you to create healthier soils, minimize chemical reliance, and grow a culture of regeneration.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Artificial intelligence–enabled image processing: Revolutionizing early plant disease detection

Heyram S.P and Sajeesh P.K.

PG student, Department of Plant Pathology, College of Agriculture, Padannakkad, Kasaragod, Kerala -671314, India.

Assistant Professor, Department of Plant Pathology, College of Agriculture, Padannakkad, Kasaragod, Kerala-671314, India.

Abstract

Crop health problems have a major influence on global food supply and quality. Detecting diseases at an early stage is vital for reducing losses and promoting sustainable farming practices. Conventional detection methods rely heavily on visual observation, which is often subjective and labour-intensive. With recent progress in Artificial Intelligence, particularly Machine Learning (ML) and Deep Learning (DL), automated tools for identifying plant diseases have become more feasible. These systems combine different stages of image analysis—such as data acquisition, image refinement, Image partitioning, attribute extraction, and pattern classification—to provide dependable diagnostic outcomes. Techniques including Random Forests, Support Vector Machines, and Convolutional Neural Networks have achieved strong performance in early disease recognition, leading to more precise monitoring, reduced labour requirements and improved scalability in agricultural management.

Introduction

Plant diseases negatively affect agricultural productivity and if they are not recognized early, they can contribute to growing food insecurity. Rapid and accurate detection is therefore essential for implementing preventive and control measures, as well as for supporting better decision-making in crop management. In recent years, the problem of disease identification has gained increasing importance. Infected plants typically display visible symptoms—such as lesions or discoloration—on leaves, stems, flowers, or fruits. Since leaf surfaces often exhibit the most prominent signs, they are commonly used for diagnosing plant health conditions. Conventional approaches to disease detection rely largely on human observation, a process that is subjective, slow and expensive, often leading to delayed responses and ineffective management. To overcome these limitations, more advanced and efficient detection techniques are being explored. Among them, image processing has proven to be a reliable and economical tool for assessing plant diseases. By analyzing digital images of leaves and other plant parts, this technology can verify the presence of infections and assess their impact on overall plant health.

AI-powered approaches for plant disease detection

Automated systems for detecting and classifying plant diseases are designed to recognize symptoms at an early stage, particularly when they first appear on leaves. Such an approach reduces the effort required to oversee large farming areas and enhances the efficiency of crop management. Depending solely on visual inspection for identifying and categorizing diseases is often unreliable and can result in lower agricultural productivity. Early and accurate detection is therefore essential for improving yields. Both farmers and agricultural specialists face significant challenges in diagnosing plant diseases effectively. Artificial Intelligence (AI) provides valuable support in this area by facilitating early recognition and classification of leaf infections before they spread to other plants. Accurate classification not only helps prevent yield losses but also strengthens different farming strategies and management practices.

Machine Learning (ML)

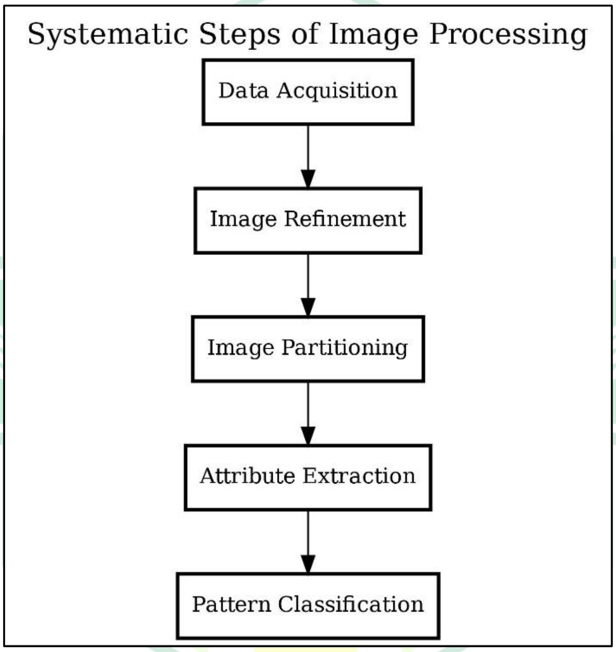
Machine Learning (ML), a branch of Artificial Intelligence (AI), allows computer systems to improve performance through experience and data exposure. In supervised learning, the model is trained using input data paired with known outputs, enabling it to make accurate predictions—for example, distinguishing between healthy and diseased plant leaves using labelled datasets. In contrast, unsupervised learning works with unlabelled data, seeking to uncover hidden structures or patterns within it.

A key distinction in ML tasks lies between classification and regression. Classification assigns data into predefined categories, such as identifying specific leaf diseases, whereas regression estimates continuous numerical values based on input features. Popular ML techniques include decision trees, random forests, k-nearest neighbours, support vector machines, and artificial neural networks. These approaches are widely applied to both classification and regression problems in agricultural disease detection.

Deep Learning (DL)

Deep Learning (DL), a specialized area within Artificial Intelligence (AI) and Machine Learning (ML), has significantly influenced domains such as image recognition, object detection and natural language processing. Unlike traditional approaches that require manual feature engineering, DL employs neural networks capable of automatically extracting relevant features from raw data. This ability enhances both the accuracy and generalization of models, particularly in visual tasks where low-level details are combined to form higher-level representations. The field encompasses a variety of neural network architectures, each tailored to specific applications. Common examples include multilayer perceptrons (MLP), backpropagation-based models (BP), deep neural networks (DNN) and convolutional neural networks (CNN).

Systematic workflow of image processing



Data acquisition

In computer vision systems, the process typically begins with acquiring images either from existing repositories or through direct field capture. The accuracy of a disease detection framework is largely dependent on the quality of these images. Factors such as camera resolution, lens properties and positioning during capture play a significant role in determining this quality. Nonetheless, images obtained in real-world settings often contain issues like noise, shadows or irrelevant background details. The effectiveness of identifying diseased regions is closely linked to how well the area of interest can be distinguished from its background. Consequently, preprocessing techniques—including noise reduction, background suppression, and image refinement—are crucial for enhancing the dependability and usefulness of the acquired images.

Image refinement

The refinement of images plays a vital role in both computer vision and image processing tasks. Raw images are often affected by factors such as noise, shadows, distortions, and cluttered backgrounds, which can reduce their quality. To address these challenges, refinement is applied as the initial stage, ensuring that images are prepared for more advanced analysis. This step also helps optimize computational efficiency by applying operations like cropping and resizing. Common preprocessing techniques include background elimination, image enhancement, conversion between colour spaces, smoothing and cropping. These approaches are widely recognized for improving image clarity and streamlining subsequent processing.

Image partitioning

Image partitioning is a technique used to divide an image into distinct regions so that significant areas can be highlighted. Its primary purpose is to separate portions that display abnormalities. By simplifying the visual content, partitioning supports easier analysis and helps distinguish between healthy and affected regions. This process is fundamental in most computer vision and image processing applications, serving as both a core technology and a critical component of image analysis.

Attribute extraction

Attributes represent key characteristics or information associated with objects, allowing them to be distinguished from one another. These attributes play a central role in object identification and in assigning class labels. Extracting attributes is a critical step in developing models for recognition and classification, as it involves selecting the traits that best describe each category. Commonly used attributes in object recognition include size, shape, colour, edges and corners. In the context of plant disease detection, attributes such as colour, texture, and shape are frequently applied to classify and identify infections. Accurate separation of diseased regions in leaf images is particularly important. Numerous studies have explored various attribute extraction approaches based on these characteristics, and the effectiveness of a disease detection system is strongly influenced by the extraction method employed. Thus, choosing suitable attributes and descriptors is essential, given that many plant diseases exhibit similar visual patterns.

Pattern classification

The classification stage is a crucial component of plant disease detection in computer vision and image processing. Its effectiveness relies on preceding steps, including data collection, preprocessing, partitioning of diseased regions and attribute extraction. In leaf-based plant disease detection systems, classification involves distinguishing between healthy and infected leaves and further categorizing infections according to their visible symptoms. This process typically employs machine learning and soft computing approaches. A dataset of leaf images is first used to train a classifier model, which is then applied to classify and recognize new test images. The classifier's role is to differentiate between healthy and diseased samples while also identifying the type of infection present.

Machine Learning and Deep Learning approaches for early detection of plant diseases

Patil *et al*. (2017) evaluated the performance of various machine learning approaches, including Random Forest (RF), Support Vector Machine (SVM), and Artificial Neural Networks (ANN), for the detection of blight disease in potato leaves. In related work, Jiang *et al*. (2019) showed that Convolutional Neural Networks (CNN) provide an efficient solution for the real-time identification of apple leaf diseases, achieving notable accuracy. Ramesh (2018) also demonstrated the effectiveness of a deep learning-based ANN model in recognizing rice blast disease in paddy leaves. Further advancements include the study by Sudhesh *et al*. (2023), who employed Dynamic Mode Decomposition (DMD) to distinguish among four major rice leaf diseases—blast, brown spot, bacterial blight, and tungro. More recently, Sudhesh *et al*. (2025) proposed RCAMNet, a multitask deep learning model capable of detecting rice bacterial leaf blight as well as analyzing its severity.

Conclusion

Timely detection of crop diseases plays a vital role in safeguarding yield and ensuring food security. Conventional visual inspection approaches are often subjective and inefficient. However, advancements in Artificial Intelligence, particularly in Machine Learning (ML) and Deep Learning (DL), have significantly enhanced the precision of disease identification. Algorithms such as Random Forests, Support Vector Machines and Convolutional Neural Networks have been widely applied to detect plant diseases from leaf images with promising results. Furthermore, integrating ML and DL models with emerging technologies such as drones and Internet of Things (IoT) systems offers powerful solutions for real-time crop monitoring. This integration enables faster decision-making, reduces losses and promotes more sustainable agricultural practices.

References

Attri, I., Awasthi, L. K., & Sharma, T. P. (2023). Machine learning in agriculture: A review of crop management applications. *Multimedia Tools and Applications, 83*, 12875–12915. https://doi.org/10.1007/s11042-023-16105-2

Bera, T., Das, A., Sil, J., & Das, A. K. (2019). A survey on rice plant disease identification using image processing and data mining techniques. In *Springer Singapore*. https://doi.org/10.1007/978-981-13-1501-5_31

Chouhan, S. S., Singh, U. P., & Jain, S. (2019). Applications of computer vision in plant pathology: A survey. *Archives of Computational Methods in Engineering*. https://doi.org/10.1007/s11831-019-09324-0

Demilie, W. B. (2023). Plant disease detection and classification techniques: A comparative study of the performances. *Journal of Big Data*, *10*, Article 63. https://doi.org/10.1186/s40537-023-00863-9

Ferentinos, K. P. (2018). Deep learning models for plant disease detection and diagnosis. *Computers and Electronics in Agriculture*, *145*, 311–318.

Fina, F., Birch, P., Young, R., Obu, J., Faithpraise, B., & Chatwin, C. (2013). Automatic plant pest detection and recognition using k-means clustering algorithm and correspondence filters. *International Journal of Advanced Biotechnology and Research*, *4*(2), 189–199.

Genitha, H. C., Dhinesh, E., & Jagan, A. (2019). Detection of leaf disease using principal component analysis and linear support vector machine. *2019 International Conference on Advanced Computing (ICoAC)*. https://doi.org/10.1109/ICoAC48765.2019.246866

Jafar, A., Bibi, N., Naqvi, R. A., Sadeghi-Niaraki, A., & Jeong, D. (2024). Revolutionizing agriculture with artificial intelligence: Plant disease detection methods, applications, and their limitations. *Frontiers in Plant Science*, *15*, 1356260. https://doi.org/10.3389/fpls.2024.1356260

Jiang, P., Chen, Y., Liu, B., He, D., & Liang, C. (2019). Real-time detection of apple leaf diseases using deep learning approach based on improved convolutional neural networks. *IEEE Access*, *7*, 59069–59080.

Kumar, G., & Bhatia, P. K. (2014). A detailed review of feature extraction in image processing systems. In *2014 International Conference on Advanced Computing and Communication Technologies (ACCT)* (pp. 5–12). https://doi.org/10.1109/ACCT.2014.74

Kumar, S., & Raghavendra, B. K. (2019). Diseases detection of various plant leaf using image processing techniques: A review. *2019 5th International Conference on Advanced Computing & Communication Systems (ICACCS)*. https://doi.org/10.1109/ICACCS.2019.8728325

Linardatos, P., Papastefanopoulos, V., & Kotsiantis, S. (2021). Explainable AI: A review of machine learning interpretability methods. *Entropy*, *23*(1), 185. https://doi.org/10.3390/e23010018

Naskath, J., Sivakamasundari, G., & Begum, A. A. S. (2023). A study on different deep learning algorithms used in deep neural nets: MLP, SOM, and DBN. *Wireless Personal Communications*, *128*, 2913–2936. https://doi.org/10.1007/s11277-022-10079-4

Palma, D., Blanchini, F., & Montessoro, P. L. (2022). A system-theoretic approach for image-based infectious plant disease severity estimation. *PLoS ONE*, *17*, 1–24.

Patil, P., Yaligar, N., & Meena, S. (2017). Comparison of performance of classifiers—SVM, RF and ANN in potato blight disease detection using leaf images. In *2017 IEEE International Conference on Computational Intelligence and Computing Research (ICCIC)* (pp. 1–5). IEEE.

Radivojević, T., Costello, Z., Workman, K., & Martin, H. G. (2020). A machine learning automated recommendation tool for synthetic biology. *Nature Communications*, *11*, 48795. https://doi.org/10.1038/s41467-020-18008-4

Rajasekaran, C., Arul, S., Devi, S., Gowtham, G., & Jeyaram, S. (2020). Turmeric plant diseases detection and classification using artificial intelligence. *2020 International Conference on Communication and Signal Processing (ICCSP)*. https://doi.org/10.1109/ICCSP48568.2020.9182255

Ramesh, S. (2018). Rice blast disease detection and classification using machine learning algorithm. In *2018 2nd International Conference on Micro-Electronics and Telecommunication Engineering (ICMETE)* (pp. 255–259). IEEE.

Saleem, M. H., Khanchi, S., Potgieter, J., & Arif, K. M. (2020). Image-based plant disease identification by deep learning meta-architectures. *Plants*, *9*(11), 1451. https://doi.org/10.3390/plants9111451

Sarker, I. H. (2021). Deep learning: A comprehensive overview on techniques, taxonomy, applications and research directions. *SN Computer Science, 2*, 420. https://doi.org/10.1007/s42979-021-00815-1

Sardogan, M., Tuncer, A., & Ozen, Y. (2018). Plant leaf disease detection and classification based on CNN with LVQ algorithm. *2018 International Conference on Computer Science and Engineering (UBMK)*. https://doi.org/10.1109/UBMK.2018.8566635

Sengar, N., Kishore, M., & Travieso, C. M. (2018). Computer vision-based technique for identification and quantification of powdery mildew disease in cherry leaves. *Computing, 100*(11), 1189–1201. https://doi.org/10.1007/s00607-018-0638-1

Sharma, M., Kumar, C. J., & Deka, A. (2022). Early diagnosis of rice plant disease using machine learning techniques. *Archives of Phytopathology and Plant Protection, 55*(3), 259–283. https://doi.org/10.1080/03235408.2021.2015866

Shoaib, M., Hussain, T., Shah, B., Ullah, I., Shah, S. M., Ali, F., et al. (2022). Deep learning-based segmentation and classification of leaf images for detection of tomato plant disease. *Frontiers in Plant Science, 13*, 1031748. https://doi.org/10.3389/fpls.2022.1031748

Sudesh, K. M., Sowmya, V., Kurian, P. S., & Sikha, O. K. (2023). AI-based rice leaf disease identification enhanced by Dynamic Mode Decomposition (DMD). *Engineering Applications of Artificial Intelligence, 123*, 105836. https://doi.org/10.1016/j.engappai.2023.105836

Sudhesh, K. M., Aarthi, R., Kurian, P. S., & Sikha, O. K. (2025). Interpretable multitask deep learning model for detecting and analyzing severity of rice bacterial leaf blight. *Scientific Reports, 15*, 27313. https://doi.org/10.1038/s41598-025-12276-0

Verma, M. (2023). Artificial intelligence role in modern science: Aims, merits, risks and its applications. *Artificial Intelligence Review, 7*, 335–342.

Wani, J. A., Sharma, S., Muzamil, M., Ahmed, S., Sharma, S., & Singh, S. (2022). Machine learning and deep learning based computational techniques in automatic agricultural diseases detection: Methodologies, applications, and challenges. *Archives of Computational Methods in Engineering, 29*, 641–677. https://doi.org/10.1007/s11831-021-09588-5

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Performance of Drum Seeded Rice (DSR) And Broadcasting Method Under Wet Irrigated Condition

P.N. Siva Prasad[1], Prabhavathi[2], I. Venkata Reddy[3], S. Krishnam Raju[4]

[1]SMS (Crop Production), KVK, Garikapadu, NTR District, Andhra Pradesh
[2]SMS (Home Science), KVK, Garikapadu, NTR District, Andhra Pradesh, India
[3]SMS (Extension), KVK, Garikapadu, NTR District, Andhra Pradesh, India
[4]Programme Coordinator, KVK, Garikapadu, NTR District, Andhra Pradesh, India

University	Acharya N.G Ranga Agricultural University
State	Andhra Pradesh
Implementing College/KVK	Dr.K.L.Rao Krishi Vigyan |Kendra, Garikapadu
Place/Village Name etc.	Nawabpeta (Village), Penuganchiprollu (Mandal), NTR (District)-
Intervention done/Initiative	Drum Seeded Rice (DSR) and Broadcasting method under wet irrigated condition
Major activity	Direct seeded rice and Drum seeder cultivation in Rice
Total no. of Beneficiaries	2000

Impact

The technology saves 7-10 days of crop duration and also helps in reducing labour cost which occurs mainly during nursery maintainance and during transplanting. On an average Rs.14,000 -16,000 per ha is saved by adopting this technology. The estimated worth of this technology is as

Sl. No	Name of specific technology/skill transferred	Extent (ha)	Increase in net returns (Rs /ha)	Economic Impact /benefit (Rs)
1.	Direct seeded rice	100	7000	21,00,000
2.	Drum seeder cultivation in Rice	9,000	12,000	10,80,00,000

Output/Results

Of the five villages and 20 farmers, two farmers namely U.Devadasu from Nawabpeta and Pedda mysaiah of Pallagiri of Nandigama division achieved success in getting higher yields by maintaining best weed management, nutrient management, timely application of agro chemicals for pest and diseases. The average yield of rice is mentioned below

1) Before Intervention 2022 (Transplanting)						
Farmer Name	**Crop**	**Area (ha)**	**Production (q/ha)**	**Gross income (Rs.)**	**Net Income (Rs.)**	**B:C Ratio**
U. Deva dasu	Paddy	1	55.50	83563	33573	1.25
G.Pedda Mysaiah	Paddy	1	50.90	79700	39100	1.40
1) After Intervention 2023 (DSR & Broadcasting)						
Farmer Name	**Crop**	**Area (ha)**	**Production (q/ha)**	**Gross income (Rs.)**	**Net Income (Rs.)**	**B:C Ratio**
U. Deva dasu	Paddy	1	56.50	85763	39513	1.85
G.Pedda Mysaiah	Paddy	1	52.80	80700	40100	1.90

Outcome/Impact

By seeing the performance of the technology, local farmers got convinced and mouth to mouth publicity among fellow farmers took place. Field day conducted in farmer's field created large impact on spread of technology. Now many farmers are adopting wet direct sowing methods of cultivation and are happy with the net profits.

Economic Benefit

The technology saves 7-10 days of crop duration and also helps in reducing labour cost which occurs mainly during nursery maintainance and during transplanting. On an average Rs.14,000 -16,000 per ha is saved by adopting this technology. The estimated worth of this technology is as

Sl. No	Name of specific technology/skill transferred	Extent (ha)	Increase in net returns (Rs /ha)	Economic Impact /benefit (Rs)
1.	Direct seeded rice	100	7000	21,00,000
2.	Drum seeder cultivation in Rice	9,000	12,000	10,80,00,000

Improvement in livelihood

Drudgery reduced, the cost of cultivation was decreased and farmer standard of living was increased.

Method demonstration of Drum seeder

Field visit of direct seeded Paddy

Distribution of drum seeder to the SC beneficiary farmers

Method demonstration on Cono weeder operation in direct seeded Paddy

Distribution of Paddy seed under SCSP

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Empowering Indian Agriculture: A Comprehensive Insight into Farmer Producer Organizations (FPOs) in India and Andhra Pradesh (2025)

I. Venkata Reddy[1], K. Achuta Raju[2], P.N. Siva Prasad[3] and N. Rajasekhar[4], T. Jeswanth Reddy[5]

[1]SMS (Extension), KVK, Garikapadu, NTR District, Andhra Pradesh
[2]Programme Coordinator, KVK, Garikapadu, NTR District, Andhra Pradesh, India
[3]SMS (Crop Production), KVK, Garikapadu, NTR District, Andhra Pradesh, India
[4]SMS (Plant Protection), KVK, Garikapadu, NTR District, Andhra Pradesh, India
[5]SMS (Veterinary Science), KVK, Garikapadu, NTR District, Andhra Pradesh, India

Abstract

Farmer Producer Organizations (FPOs) have emerged as a transformative approach to strengthen the agricultural sector in India. These collectives aim to enhance the bargaining power, production capabilities, and income of small and marginal farmers by organizing them into formal business entities. This article explores the concept and significance of FPOs, their current status in India as of 2025, key institutions supporting their growth, and a detailed review of the progress and challenges of FPOs in Andhra Pradesh. The paper highlights how FPOs are redefining the role of farmers from mere producers to agripreneurs, ensuring sustainable development and rural empowerment.

Introduction

Indian agriculture, traditionally characterized by fragmented landholdings and low-income levels, is undergoing a structural transformation. With over 86% of Indian farmers being small and marginal, collective action has become crucial for addressing production, marketing, and credit-related challenges. Farmer Producer Organizations (FPOs) have emerged as a key strategy to empower farmers by providing them with access to better inputs, technology, finance, and markets.

An FPO is a legal entity formed by primary producers, including farmers, milk producers, fishermen, weavers, rural artisans, and craftsmen. The concept has gained momentum since the early 2000s and has received significant policy support from the Government of India and various financial and developmental institutions.

Status of FPOs in India (2025)

As of 2025, India has witnessed significant growth in the establishment and operationalization of FPOs. According to recent government data:

- **Over 21,000 FPOs** have been registered across the country.
- The **Central Sector Scheme on Formation and Promotion of 10,000 FPOs**, launched in 2020, has catalyzed the growth of farmer collectives by offering financial assistance, institutional support, and capacity-building initiatives.
- FPOs are now actively involved in agri-input supply, aggregation, processing, branding, and marketing, playing a pivotal role in value chain integration.

Despite this progress, challenges such as lack of professional management, limited market access, inadequate infrastructure, and financial literacy remain barriers to their full potential.

Advantages of Farmer Producer Organizations (FPOs)

1. **Improved Bargaining Power**

FPOs allow small and marginal farmers to unite and operate as a collective, which significantly enhances their bargaining power. Whether it's purchasing inputs like seeds and fertilizers or selling their produce, FPOs enable members to negotiate better prices and terms than they could individually.

2. **Access to Quality Inputs at Lower Costs**

By purchasing inputs in bulk, FPOs can procure seeds, fertilizers, pesticides, and equipment at wholesale rates. These cost savings are passed on to members, reducing their production costs and improving profitability.

3. **Better Market Linkages**
FPOs act as intermediaries between farmers and markets. They help aggregate produce, grade and standardize it, and connect farmers directly to buyers such as wholesalers, retailers, exporters, and agri-processors. This helps farmers avoid middlemen and receive fair market prices.
4. **Value Addition and Processing**
Many FPOs engage in value addition activities like cleaning, sorting, grading, packaging, and primary processing of farm produce. This enhances the market value of the product and opens up new income avenues for farmers.
5. **Access to Credit and Finance**
FPOs can access institutional credit more easily than individual farmers. Banks and financial institutions are more willing to lend to collective entities. Some government schemes also provide credit guarantees and equity grants to support FPOs.
6. **Capacity Building and Skill Development**
Members of FPOs benefit from training programs, workshops, and exposure visits organized by promoting institutions. These initiatives improve their technical knowledge, business skills, and awareness of modern farming practices and market trends.
7. **Government Support and Subsidies**
FPOs are eligible for various government schemes and subsidies under programs such as the Central Sector Scheme on Promotion of 10,000 FPOs, PM FME (Formalization of Micro Food Processing Enterprises), and e-NAM integration. These benefits are often not accessible to individual farmers.
8. **Improved Risk Management**
By working as a group, FPO members can pool resources and share risks related to production, price volatility, and climate change. Some FPOs also facilitate crop insurance and disaster relief mechanisms for their members.
9. **Enhanced Storage and Infrastructure Facilities**
FPOs can collectively invest in infrastructure like warehouses, cold storage, grading units, and transport facilities. This helps reduce post-harvest losses and improves supply chain efficiency.
10. **Women and Youth Empowerment**
FPOs also provide opportunities for marginalized groups, including women and rural youth, to participate in economic activities. Women-led FPOs are emerging as powerful platforms for gender empowerment in rural areas.

Institutions that promote FPOs in India

Several government and non-government institutions are playing a vital role in the formation, funding, and capacity building of FPOs:

1. **Small Farmers Agribusiness Consortium (SFAC)**
   - Nodal agency for the promotion of FPOs under the Ministry of Agriculture & Farmers Welfare.
   - Provides equity grants, credit guarantee support, and training.
2. **National Bank for Agriculture and Rural Development (NABARD)**
   - Offers grant support, formation assistance, and capacity-building programs through Producer Organization Promoting Institutions (POPIs).
3. **National Cooperative Development Corporation (NCDC)**
   - Provides financial assistance to cooperative societies and FPOs for value addition and infrastructure.
4. **State Governments**
   - Run FPO-focused schemes and integrate FPOs with state-level agri-marketing reforms and procurement systems.
5. **NGOs, CSOs, and Private Sector Players**
   - Act as POPIs, offering technical guidance, market linkage, and mentoring to grassroots-level organizations.

Status of FPOs in Andhra Pradesh

Andhra Pradesh is one of the leading states in India in promoting and nurturing FPOs, driven by proactive government initiatives and a strong agricultural base.

- As of 2025, **more than 1,500 FPOs** are functional in the state.
- The **Andhra Pradesh State Agros Development Corporation and RySS (Rythu Sadhikara Samstha)** have been instrumental in mobilizing farmers into sustainable collectives.
- The state government has aligned FPO promotion with its broader agricultural transformation goals, such as natural farming, digital agriculture, and climate resilience.

Key sectors where FPOs in Andhra Pradesh are making an impact include:

- Horticulture (mango, banana, citrus fruits)
- Pulses and millets
- Dairy and livestock
- Fisheries and aquaculture

FPOs are also playing a significant role in linking farmers to electronic National Agriculture Market (e-NAM), input subsidies, and financial institutions.

Strategic Blueprint to Strengthen FPOs in India

To truly unlock the transformative potential of Farmer Producer Organizations (FPOs), India must move beyond formation targets and focus on building resilient, self-sustaining farmer enterprises. A strategic approach rooted in **long-term vision, localized solutions, and inclusive partnerships** is key. Here's a forward-looking, actionable roadmap:

1. Localized Leadership Development

Build strong second-line leadership within FPOs by identifying and mentoring local farmer leaders—not just directors or CEOs, but grassroots members who can mobilize trust and action. These leaders should be trained in agri-business management, negotiation, and governance through region-specific, language-adapted modules delivered at the village level.

2. Business Diversification Tailored to Agro-Ecology

Encourage FPOs to move beyond crop aggregation and adopt region-specific enterprises such as seed production, agri-tourism, bee-keeping, medicinal plants, or food processing. Every FPO should be guided to create a 3-year business diversification plan aligned with their agro-climatic conditions and local demand.

3. Integrated Digital Ecosystem

Establish a unified digital backbone for FPOs that goes beyond record-keeping. This platform should integrate inventory tracking, market prices, customer databases, logistics, weather alerts, financial dashboards, and live advisory—all accessible through mobile phones, even offline. Encourage use of vernacular interfaces and voice-enabled tech for inclusivity.

4. Cluster-Based Mentorship Hubs

Set up "FPO Mentorship Hubs" across clusters of 15–20 FPOs. Each hub should host an experienced agri-business mentor, a financial advisor, and a digital technician. These hubs act as traveling knowledge centers—hand-holding FPOs with business planning, legal compliance, branding, and market outreach.

5. Market Contract Intelligence Cells

Create dedicated cells at district level to support FPOs in understanding and negotiating contract farming agreements. These cells would decode legal clauses, ensure fair trade, monitor compliance, and resolve disputes—thereby protecting farmers from exploitative contracts.

6. Shared Infrastructure Cooperatives

Promote co-investment models where multiple FPOs co-own and manage post-harvest infrastructure such as dryers, cold storage, packaging units, or transport vehicles. This reduces capital burden on individual FPOs and promotes cooperative governance models across value chains.

7. Youth-Led Innovation Labs

Establish village-based innovation labs led by rural youth, in partnership with agri-tech startups and educational institutions. These labs serve as problem-solving hubs for FPOs, piloting new ideas such as precision farming, regenerative practices, or local branding strategies.

8. FPO Credit Intelligence Reports (FCIRs)
Introduce FPO-specific credit scoring mechanisms that track operational history, market linkages, governance practices, and repayment capacity—allowing banks to assess creditworthiness beyond traditional collateral systems. This would unlock customized financial products for FPOs.

9. Farmer-Centric Brand Creation
Encourage each FPO to create its own brand identity by narrating the story of the farmers behind the product—where it's grown, who grows it, and how. Link these stories with QR codes on packaging to build consumer trust and differentiate farmer produce in competitive markets.

10. Transparent Performance Scorecards
Develop real-time performance scorecards that track each FPO's health based on business growth, member participation, governance quality, and sustainability practices. These scorecards should be made accessible to members, funders, and policymakers to ensure accountability and targeted support.

Conclusion
FPOs represent a cornerstone in India's agricultural policy aimed at doubling farmers' income and ensuring sustainable rural livelihoods. With consistent support from both central and state governments, along with proactive involvement of financial and civil society organizations, FPOs have the potential to revolutionize Indian agriculture. Andhra Pradesh serves as a model of how decentralized, farmer-led institutions can drive inclusive agricultural development. However, addressing structural bottlenecks and building long-term institutional capacities remains critical for the success of the FPO movement.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

"Use of Bioindicators like Melanophores for Monitoring Aquatic Pollution"

Trapti Pathak

School of Sciences, ITM University, Gwalior

Abstract

Aquatic ecosystems are increasingly threatened by various pollutants, including heavy metals, pesticides, industrial effluents, and pharmaceutical residues. Traditional methods of water quality monitoring often involve complex, time-consuming chemical analyses. As a complementary and cost-effective alternative, the use of biological indicators—or bioindicators—has emerged as a valuable approach in eco-toxicology. Among these, melanophores, the pigment-containing cells in fish skin, have shown remarkable sensitivity to environmental changes and toxic substances. This article explores the role of melanophores in freshwater teleost as responsive bioindicators for aquatic pollution. The physiological mechanisms underlying pigment dispersion and aggregation in response to chemical stressors are discussed, particularly the influence of adrenergic and hormonal pathways. Case studies involving exposure to specific pollutants and their visible effects on melanophores behavior are presented to demonstrate their practical utility. The advantages of using melanophores include real-time visual assessment, species-specific sensitivity, and non-invasive observation, making them suitable for both laboratory and field-based monitoring. This review advocates for integrating melanophore-based bioassays into environmental monitoring frameworks to enhance early detection of aquatic contamination and support sustainable water resource management.

Key Words: Melanophores, Bioindicators, Aquatic Pollution, Ecotoxicology, Chemical Stressors, Adrenergic Pathways

Introduction:

Aquatic ecosystems are vital for biodiversity, human livelihoods, and maintaining ecological balance. However, these ecosystems are increasingly threatened by various pollutants such as heavy metals, pesticides, industrial waste, and pharmaceutical residues. Monitoring water quality and detecting pollution early is essential for protecting aquatic life and ensuring safe water for human consumption.

Traditional chemical analyses for water quality, though accurate, can be expensive, time-consuming, and require sophisticated instruments. As a complementary approach, biological indicators—organisms or their physiological responses sensitive to environmental changes—have gained prominence in Ecotoxicology. Among these, melanophores, specialized pigment cells found in many freshwater fish species, have emerged as valuable Bioindicators due to their rapid and visible response to pollutants.

What Are Melanophores?

Melanophores are specialized pigment cells belonging to a broader group called **chromatophores**, which are responsible for coloration and color changes in many aquatic animals such as fish, amphibians, and reptiles. Among chromatophores, melanophores specifically contain **melanin**, a dark pigment that gives these cells their characteristic black or brown color.

Inside melanophores, melanin is stored in tiny, membrane-bound organelles called **melanosomes**. The key feature of melanophores is their ability to **change the distribution of these melanin granules within the cell**. When melanosomes disperse evenly throughout the cytoplasm, the cell—and consequently the skin—appears darker. Conversely, when melanosomes aggregate tightly near the cell's center (around the nucleus), the cell appears lighter or more translucent.

This dynamic pigment movement enables fish and amphibians to adapt their coloration rapidly for various purposes, such as **camouflage**, **communication**, **temperature regulation**, and **stress responses**.

Regulation of Melanophore Pigment Movement:

The dispersion and aggregation of melanin granules in melanophores are regulated by complex biochemical mechanisms involving:

- **Neurohormonal Control:** Signals from the nervous system and endocrine hormones like **melanin-concentrating hormone (MCH)** and **melanocyte-stimulating hormone (MSH)** influence pigment positioning. For example, MSH promotes pigment dispersion, causing darkening, while MCH causes aggregation, leading to lightening.
- **Adrenergic Signaling:** Neurotransmitters like **epinephrine (adrenaline)** and **norepinephrine** bind to adrenergic receptors on melanophores, triggering intracellular pathways that induce rapid pigment aggregation. This is often part of the animal's immediate stress response.
- **Intracellular Mechanisms:** The movement of melanosomes is mediated by the cytoskeleton components—microtubules and actin filaments—and motor proteins such as kinesin and dynein that transport melanosomes to different parts of the cell.

Biological Significance:

The ability of melanophores to change pigment distribution enables fish to:

- Adjust camouflage against varying backgrounds.
- Signal mood, reproductive status, or social rank to conspecifics.
- Protect against ultraviolet radiation by increasing skin darkness.
- Respond to environmental stressors, including temperature changes and pollutants.

Because melanophores react sensitively and visibly to chemical and physical changes in their environment, they serve as excellent **bioindicators** for monitoring aquatic ecosystem health.

Mechanism of Melanophore Response to Pollutants

Melanophores respond to environmental changes through intricate cellular signaling mechanisms that control the movement of melanin granules within the cell. However, when aquatic organisms are exposed to pollutants, these normal regulatory pathways can be disrupted, leading to abnormal pigment distribution and visible changes in coloration. Understanding these mechanisms helps researchers use melanophores as effective bioindicators of aquatic pollution.

*1. **Adrenergic Compounds and Melanin Aggregation***

Certain pollutants or xenobiotics act similarly to **adrenergic neurotransmitters** like **epinephrine (adrenaline)** and **norepinephrine**. These compounds bind to **adrenergic receptors** located on the surface of melanophores, activating intracellular signaling cascades primarily involving **cyclic AMP (cAMP)** and **calcium ions (Ca^{2+})**.

- Activation of these receptors often results in **aggregation** of melanin granules toward the cell center.
- This aggregation causes the fish's skin to lighten, as fewer melanosomes are dispersed to cover the cell's cytoplasm.
- For example, exposure to pollutants that mimic or induce adrenergic responses can lead to rapid pigment aggregation, serving as a visible marker of chemical stress.

*2. **Effects of Heavy Metals and Pesticides***

Heavy metals such as **cadmium (Cd)**, **mercury (Hg)**, and **lead (Pb)**, along with pesticides like organophosphates, can enter aquatic environments through industrial discharge, agricultural runoff, or mining activities.

- These pollutants generate **oxidative stress** by increasing the production of reactive oxygen species (ROS), which damage cellular components, including proteins and DNA.
- Oxidative stress in melanophores interferes with **calcium signaling pathways**, crucial for the transport of melanosomes along microtubules.
- Disruption in calcium homeostasis can alter the balance between melanin dispersion and aggregation, resulting in either abnormal darkening or lightening of the skin.
- Furthermore, heavy metals may inhibit or activate enzymes involved in neurotransmitter metabolism, indirectly affecting melanophore responses.

*3. **Interference with Neurohormonal Regulation***

Melanophore pigment movement is also tightly regulated by hormones such as **melanocyte-stimulating hormone (MSH)** and **melanin-concentrating hormone (MCH)**. Pollutants can disturb the synthesis, release, or receptor binding of these hormones:

- Some chemicals act as **endocrine disruptors**, altering normal hormonal signaling pathways.

- This hormonal imbalance can lead to irregular pigment dispersion patterns—such as incomplete aggregation or persistent dispersion—that deviate from natural physiological responses.
- Abnormal pigment patterns often correlate with sub-lethal toxic effects, indicating ongoing environmental stress before mortality or other visible damage occurs.

Implications for Pollution Monitoring

By observing these physiological changes in melanophores—such as unusual pigment aggregation, dispersion, or irregular patterns—scientists can detect the presence of specific classes of pollutants or general environmental stress.

- Changes in melanophore behavior are **early warning signals** of aquatic contamination.
- Because these responses are often species-specific, monitoring multiple indicator species can provide comprehensive data on water quality.
- Coupling melanophore observations with molecular or biochemical assays enhances the precision of pollution assessments.

Applications and Case Studies

The unique physiological response of melanophores to environmental pollutants has been extensively studied and applied in various research contexts to monitor aquatic pollution. Below are some significant examples illustrating how melanophores serve as practical bioindicators in real-world scenarios:

*1. **Heavy Metal Exposure***

Heavy metals such as **mercury (Hg)**, **cadmium (Cd)**, and **lead (Pb)** are among the most hazardous pollutants found in aquatic environments due to their toxicity and persistence.

- In several studies, fish species exposed to mercury-contaminated waters exhibited **marked melanin aggregation** in their melanophores.
- This pigment aggregation manifests as a visible **lightening of skin coloration**, which correlates strongly with mercury concentration in the water.
- Such changes are detectable even before the onset of overt physiological damage or mortality, making melanophore response an early and sensitive marker of heavy metal toxicity.
- For example, experiments with freshwater teleosts demonstrated that even low levels of mercury exposure caused significant changes in pigment distribution, which could be monitored visually or microscopically.

This application highlights the potential of melanophores for **rapid screening** of heavy metal pollution in aquatic habitats, especially in regions where access to advanced chemical testing is limited.

*2. **Impact of Pesticides***

Pesticides, particularly **organophosphates** and **carbamates**, are commonly used in agriculture but often enter water bodies through runoff, posing risks to aquatic fauna.

- Research has shown that fish exposed to organophosphate pesticides experience **altered melanophore pigment patterns**, often displaying abnormal **dispersion or aggregation** depending on the nature and concentration of the chemical.
- These pigment changes can be quantitatively linked to pesticide concentration, providing a **dose-dependent visual biomarker** for contamination levels.
- In controlled laboratory bioassays, species like *Oreochromis* (tilapia) and *Cyprinus carpio* (common carp) have shown consistent melanophore responses when exposed to sub-lethal doses of pesticides.
- Such assays are useful for **environmental risk assessment** and for monitoring pesticide runoff in agricultural catchments.

*3. **Pharmaceutical Contaminants***

The increasing presence of pharmaceutical residues—such as antibiotics, analgesics, and hormones—in freshwater systems has become a growing environmental concern.

- Studies have begun exploring the effects of these synthetic compounds on fish melanophores to evaluate their toxicity.

- Certain pharmaceuticals have been observed to interfere with normal pigment regulation, causing either persistent pigment dispersion or aggregation.
- These changes serve as indicators of pharmaceutical contamination and its sub-lethal effects on aquatic organisms.
- For instance, exposure to synthetic adrenergic drugs has been shown to mimic natural hormonal responses, resulting in measurable pigment shifts in melanophores.

Practical Use of Melanophore Bioassays

- **Laboratory Applications:** In controlled settings, melanophore responses are used to conduct toxicity assays, screen chemicals for harmful effects, and understand pollutant mechanisms.
- **Field Applications:** Observations of melanophore pigmentation changes in wild fish populations offer a **cost-effective, non-invasive** method for on-site monitoring of water quality.
- **Advantages:** These bioassays provide rapid results, require minimal equipment, and can be performed by trained personnel without extensive laboratory facilities.

  Note: Together, these case studies demonstrate how melanophores serve as reliable, sensitive bioindicators across different classes of aquatic pollutants. Their integration into environmental monitoring programs can facilitate timely pollution detection and promote sustainable management of freshwater ecosystems.

Advantages and Limitations:

Advantages

1. **Cost-effective Compared to Chemical Assays**

Traditional chemical analyses for detecting aquatic pollutants often require expensive reagents, sophisticated instruments, and trained personnel. In contrast, using melanophores as bioindicators involves relatively simple observational techniques, reducing the overall cost of monitoring programs. This makes melanophore-based assays accessible and practical for resource-limited settings, such as rural areas or developing countries, where advanced laboratory facilities may not be available.

2. **Real-time and Visual Assessment**

Melanophores exhibit **rapid physiological responses** to pollutants, with visible pigment dispersion or aggregation occurring within minutes to hours after exposure. This allows researchers and environmental managers to assess water quality **immediately**, without waiting for lengthy laboratory analyses. Because the changes are often visible to the naked eye or through simple microscopy, assessments can be conducted on-site, enabling quick decision-making and early detection of pollution events.

3. **Non-destructive and Ethical Monitoring**

Monitoring melanophore responses usually requires minimal handling or non-invasive observations of live fish, avoiding the need for sacrificing animals. This approach supports ethical research practices by reducing animal harm. Furthermore, fish can often be returned to their natural habitat after monitoring, allowing for repeated observations over time and minimizing ecological disturbance.

4. **Can Be Combined with Molecular and Biochemical Analyses for Comprehensive Evaluation**

While melanophore responses provide valuable visual cues, combining them with molecular techniques—such as gene expression studies, enzyme assays, or biomarker analysis—enhances the accuracy and depth of pollution assessments. Such integrative approaches enable researchers to identify specific toxic effects at the cellular or molecular level while benefiting from the rapid screening capability of melanophore bioassays.

Limitations

1. **Sensitivity May Vary with Species and Environmental Factors**

Different fish species possess varying sensitivities to pollutants and may exhibit diverse melanophore responses. Environmental variables such as temperature, pH, salinity, and light conditions can also influence pigment cell behavior independently of pollution, potentially confounding results. Therefore, species selection and environmental context must be carefully considered to ensure accurate interpretation.

2. **Requires Baseline Data to Interpret Pigment Changes Accurately**

To differentiate pollution-induced pigment changes from normal physiological variations, it is essential to establish baseline melanophore patterns for the species and environment under study. Without such reference data, it can be challenging to determine whether observed pigment alterations are due to contaminants or natural fluctuations related to factors like circadian rhythms, reproductive status, or stress unrelated to pollution.

3. **May Not Identify Specific Pollutants but Indicates General Pollution Stress**

While melanophore responses effectively signal the presence of chemical stress, they typically do not provide information about the exact nature or concentration of the pollutants involved. Therefore, melanophore bioassays are best used as **early warning tools** that indicate overall water quality issues, which can then be followed up with targeted chemical analyses to identify specific contaminants.

Future Perspectives

The future of melanophore-based bioassays lies in their integration with emerging technologies to improve accuracy and usability. Advanced **image analysis software** can objectively quantify pigment changes, reducing observer bias and enabling precise monitoring even in field conditions. Coupling these assays with **molecular markers** and genetic tools can provide deeper insights into pollutant-specific effects, enhancing both sensitivity and specificity.

Additionally, the development of **portable, user-friendly devices** for real-time, on-site detection of melanophore responses would make aquatic pollution monitoring more accessible and efficient, especially in remote or resource-limited areas.

Beyond technology, **community engagement and education** play a crucial role. Training local fishers, farmers, and citizen scientists to use melanophore bioindicators empowers communities to actively participate in water quality monitoring and conservation efforts, fostering sustainable environmental stewardship.

Conclusion

Melanophores serve as an effective and promising bioindicator for the detection and monitoring of aquatic pollution. Their ability to exhibit clear, rapid physiological changes in response to environmental contaminants provides a practical, visual, and cost-efficient method for assessing water quality. Unlike conventional chemical tests, melanophore-based bioassays enable early detection of pollution stress, allowing timely intervention before irreversible ecosystem damage occurs. Integrating these bioassays into routine environmental monitoring can significantly enhance the ability of scientists and policymakers to track pollution trends, design targeted conservation strategies, and safeguard freshwater biodiversity. Ultimately, employing melanophores in water quality management contributes to the sustainable preservation of aquatic ecosystems for current and future generations.

References

Bagnara, J. T., Matsumoto, J., & Fernandez, P. J. (2012). Comparative anatomy and physiology of pigment cells in nonmammalian tissues. *Pigment Cell & Melanoma Research*, 25(1), 30–47. https://doi.org/10.1111/j.1755-148X.2011.00892.x

Chatterjee, S., Kumar, V., & Kumar, A. (2016). Heavy metal pollution and fish melanophores: A review on morphological and physiological changes. *Environmental Toxicology and Pharmacology*, 48, 166-172. https://doi.org/10.1016/j.etap.2016.08.009

Fudge, D. S. (2000). Epithelial melanophores of fish: Morphology and physiology. *Microscopy Research and Technique*, 50(3), 243-250. https://doi.org/10.1002/1097-0029(20001115)50:3<243::AID-JEMT2>3.0.CO;2-6

Fujii, R. (2000). The regulation of motile activity in fish chromatophores. *Pigment Cell Research*, 13(5), 300–319. https://doi.org/10.1034/j.1600-0749.2000.130502.x

Heath, A. G. (1995). Water pollution and fish physiology. *CRC Press*. https://doi.org/10.1201/9781420037365

Mallatt, J., & Wang, Y. (2000). Responses of fish melanophores to toxicants: Role in ecotoxicology. *Aquatic Toxicology*, 48(3-4), 361-372. https://doi.org/10.1016/S0166-445X(99)00098-6

McClure, M. M., & Pawluk, M. J. (2008). Melanophore-based assays for detecting waterborne toxins. *Journal of Environmental Monitoring*, 10(5), 573-579. https://doi.org/10.1039/B804470F

Olsson, P. E., & Carney, T. J. (2009). Pigment pattern development and evolution in fish melanophores: Implications for environmental monitoring. *BioEssays*, 31(11), 1163-1174. https://doi.org/10.1002/bies.200900053

Riar, A. S., & Sood, P. (2013). Effects of organophosphate pesticides on fish pigment cells: A bioindicator approach. *Environmental Monitoring and Assessment*, 185(9), 7835-7843. https://doi.org/10.1007/s10661-013-3170-0

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

THE DARK SIDE OF MILLET CULTIVATION

Shivangi Tripathy

Research Scholar (PG), Department of food Nutrition and Public Health,
SHUATS, Prayagraj, U.P.

ABSTRACT

Millet crops are extensively cultivated in numerous parts of the world, particularly insemi-arid and arid regions. While millet is a drought- resistant crop that requires minimum inputs, its intensive civilization can have devastating effects on the soil and ecosystem. Millet cultivation has been touted as a sustainable and climate-flexible crop, particularly insemi-arid and arid regions. However, the intensive civilization of millet can have far-reaching environmental consequences that threaten the long- term productivity and sustainability of crop fields. Millets are a group of small-grained cereals that have been cultivated for thousands of years, particularly in Asia and Africa. They're rich in nutrients, drought-tolerant, and bear minimum inputs, making them an ideal crop for small- scale farmers and borderline lands. Millets are a vital element of sustainable agriculture, food security, and pastoral development.

INTRODUCTION

Millets are traditional grains, grown and consumed in the Indian subcontinent from the history further than 5000 years. Millets are small- granulated, periodic, warm- weather cereals belonging to grass family. They're rain- fed, hardy grains which have low requirements of water and fertility when compared to other popular cereals. They're largely tolerant to drought and other extreme weather conditions. Millets are nutri cereals comprising of sorgum, plum millet, cutlet millet (Major millets) foxtail, little, kodo, proso and barnyard millet (minor millets). These are one of the oldest foods known to humanity. These are one of the several species of coarse cereal grasses in the family poaceae, cultivated for their small comestible seeds. mock millets are so called because they aren't part of the **Poaceae** botanical family, to which 'true' grains belong, still they're nutritionally analogous and used in analogous ways to 'true' grains. Millets are largely nutritional, non-glutinous and non-acid forming foods. Millets have numerous nutraceutical and health promoting properties especially the high fibre content. Millets act as a probiotic feeding for micro- flora in our inner ecosystem.

TYPES OF MILLETS

1. **Sorghum (Jowar)**
   Sorghum is one of the highest-yielding millets, with average productivity ranging from **1.2 to 2.5 tons per hectare** depending on soil fertility and rainfall. In irrigated and improved conditions, yields may even reach up to **3–4 tons per hectare**. Its biggest advantage is that it can thrive in **semi-arid and drought-prone regions**, where other cereals fail. Jowar requires very little water compared to rice and wheat, which reduces the burden on groundwater. It also improves **soil structure and fertility** through organic matter recycling from its residues. Sorghum's deep root system prevents soil erosion and helps in carbon sequestration. From a socio-economic perspective, it provides a stable livelihood for farmers in marginal areas and ensures food security during dry seasons. Its resilience against pests and ability to withstand harsh climates make it a **climate-smart crop**, crucial for sustainable agriculture.
2. **Pearl millet (Bajra)**
   Pearl millet has a yield potential of **1.0–2.5 tons per hectare**, though in well-managed farms, yields can go up to **3.5 tons per hectare**. It is extremely **tolerant to drought, high temperatures, and poor soils**, making it a preferred crop in Rajasthan, Gujarat, and semi-arid regions of Africa. Bajra grows well in sandy soils where other cereals cannot survive, and it requires **30–40% less water than wheat or rice**, making it water-efficient. Its short growing season (70–85 days) allows farmers to harvest quickly and even grow it as an intercrop with pulses or legumes, which improves soil fertility. Pearl millet stubbles are used as fodder for cattle, adding to its farming value. It plays an important role in combating food insecurity in harsh climates and is seen as a **sustainable grain for the future**, particularly under global warming scenarios.

3. **Foxtail millet (Kangni)**
Foxtail millet generally yields **1.0–2.0 tons per hectare**, depending on soil fertility and rainfall. It is a **short-duration crop (75–90 days)**, which makes it highly suitable for multi-cropping and crop rotation systems. Farmers benefit as it requires minimal irrigation and grows well on marginal and degraded soils. The crop's low input requirement (fertilizers and pesticides) reduces production costs, making it eco-friendly and economically viable. Foxtail millet contributes to **soil health restoration** by reducing nutrient depletion and supporting crop diversification. It also helps in weed suppression due to its dense canopy. From an environmental perspective, it requires significantly less water compared to rice and wheat, which reduces water stress in dryland farming areas. With rising demand for millet-based foods, foxtail millet cultivation has a **positive impact on farmer incomes**, promoting sustainable livelihoods in dry regions.

4. **Finger millet (Ragi)**
Finger millet has an average yield of **1.2–2.0 tons per hectare**, though with improved varieties and good management, yields can exceed **3.5 tons per hectare**. It is a **low-input crop** that thrives in rainfed conditions and requires very little irrigation. Ragi is often grown in hilly and dry regions such as Karnataka, Tamil Nadu, and Uttarakhand, where it helps prevent soil erosion due to its strong root network. Its ability to grow in poor soils, including lateritic and sandy soils, makes it invaluable for marginal farmers. From a farming perspective, finger millet is highly resistant to pests and diseases, reducing the need for chemical pesticides. It is also stored for long periods without spoilage, ensuring **food security** during droughts and lean seasons. Cultivation of Ragi supports small-scale farmers, promotes biodiversity, and acts as a **resilient crop under climate change**.

5. **Proso millet (Barri)**
Proso millet is a **short-duration crop** (60–75 days) with a yield potential of **0.8–1.8 tons per hectare**, making it one of the fastest-growing grains. Its rapid maturity allows it to be cultivated as a **catch crop** between two major crop cycles, ensuring year-round income for farmers. It thrives on marginal and degraded soils, requiring very little water and minimal fertilizer inputs. Proso millet is also naturally resistant to many diseases, which lowers dependence on pesticides. From an ecological perspective, it is one of the best crops for **resource-poor farmers**, as it restores soil fertility when grown in rotation with legumes. Its cultivation reduces pressure on groundwater and prevents land degradation. Economically, proso millet provides farmers with an additional source of food and income, while environmentally, it enhances agro-biodiversity, making it an important **sustainable crop for food security**.

6. **Little millet (Kutki)**
Little millet yields about **0.9–1.7 tons per hectare**, though under improved farming conditions, it can reach up to **2.5 tons per hectare**. Its biggest advantage is that it matures in just **90–100 days**, making it a reliable option for farmers in drought-prone areas. The crop is hardy and grows well in poor, gravelly soils where other cereals fail. It requires very little irrigation, thus conserving water resources. Little millet is often used as an **intercrop with pulses**, which improves soil fertility through nitrogen fixation. It is also resistant to many common pests and diseases, which reduces chemical input costs for farmers. Environmentally, it contributes to **crop diversity and resilience against climate variability**. For small farmers, particularly in tribal areas, little millet is a dependable grain that provides food security, animal fodder, and stable income, while conserving natural resources.

7. **Barnyard millet (Jhangora)**
Barnyard millet is one of the **fastest-growing millets**, maturing in just **45–60 days**, with yields ranging from **0.8–1.5 tons per hectare**. This short duration allows farmers to cultivate it as a **famine reserve crop**, especially during drought years. It grows well in hilly regions and poor soils with minimal irrigation, making it ideal for regions with erratic rainfall. From a sustainability perspective, barnyard millet requires very low inputs, which reduces the environmental burden of chemical fertilizers and pesticides. Its dense root system prevents **soil erosion**, especially on slopes and hills. Additionally, it improves soil organic matter and helps maintain ecological balance. Farmers benefit because barnyard millet can be grown even on marginal lands where other crops cannot survive, ensuring **food and livelihood security**. It plays a key role in **climate-resilient farming systems**, making it an invaluable millet for the future.

IMPACT OF MILLET CROPS ON FIELD

Millet cultivation has a significant impact on the field, affecting its physical, chemical, and natural properties. Ferocious millet cultivation can lead to soil contraction, reducing its water infiltration capacity and adding run off and erosion risk. The repeated use of chemical fertilizers and pesticides can alter soil pH, deplete nutrient reserves, and harm salutary microorganisms. Also, millet's expansive root system can lead to soil humidity reduction, affecting posterior crops. still, millet civilization also has positive goods, similar as perfecting soil structure through its expansive root system, adding organic matter, and furnishing soil cover, reducing corrosion. Likewise, millet's failure tolerance and low water conditions make it an ideal crop for water-scarce areas, reducing the pressure on groundwater resources. Overall, millet civilization can have both salutary and mischievous goods on the field, pressing the need for sustainable agrarian practices to minimize negative impacts while maximizing benefits.

Soil Nutrient Depletion- Millet crops are heavy feeders, taking large quantities of nutrients to grow. However, the soil can come depleted of essential nutrients like nitrogen, phosphorus, If proper crop gyration and fertilization practices aren't followed. This can lead to reduced fertility and dropped crop yields, making it challenging for growers to maintain soil health.

Water Depletion- Millet crops bear significant quantities of water, especially during the flowering and grain-filling stages. Over-extraction of groundwater for irrigation can lead to water reduction, affecting not only millet crops but also other crops and ecosystems that calculate on the same water source. Biodiversity Loss-Monoculture millet civilization can lead to a loss of biodiversity, as other crops and shops are replaced by millet. This can have cascading goods on the ecosystem, including reduced pollination, increased pest pressure, and dropped ecosystem adaptability. The loss of biodiversity can also affect the long- term productivity and sustainability of crop fields, making it challenging for growers to maintain soil health and fertility.

Soil Salinization- Irrigation for millet crops can lead to soil salinization, especially in areas with poor drainage. Salt build up in the soil can reduce crop yields, affect soil structure, and make the land infelicitous for other crops. Soil declination nonstop millet civilization without proper crop gyration and soil operation can lead to soil declination. To alleviate these disadvantages, sustainable millet civilization practices should be espoused, similar as Agroecological practices ,Crop rotation and intercropping, Organic husbandry , Integrated pest operation, Soil conservation measures, Effective water use , minimum use of chemical inputs , Proper waste operation .

CONCLUSION

In conclusion, millet civilization has a profound impact on the terrain, soil, and ecosystem. While millets are a vital crop for food security and sustainable agriculture, their civilization can lead to soil declination, nutrient reduction, and corrosion if not managed sustainably. The ferocious civilization of millets can affect in soil contraction, salinization, and loss of biodiversity, eventually affecting soil health and productivity. still, by espousing sustainable practices similar as crop rotation, organic emendations, conservation tillage, cover cropping, integrated nutrient operation, soil testing, and agroforestry, the negative impacts of millet civilization can be eased. These practices promote soil conservation, reduce corrosion, and enhance soil fertility, structure, and biodiversity. also, millets are a climate- flexible crop, adaptable to challenging surroundings, and bear minimum inputs, making them an ideal crop for small- scale growers and borderline lands. thus, it's essential to borrow sustainable millet cultivation practices to insure long- term soil health, ecosystem balance, and food security while minimizing environmental degradation. By doing so, we can harness the benefits of millets while guarding the environment and promoting sustainable agriculture.

REFERENCE

Kumar, P., & Kumar, V. (2020). Environmental Impacts of Millet Cultivation. Journal of Sustainable Agriculture and Environment (italics). 14(2): 12-20.

A.K. Jha, S.B. Singh, and V.K. Jha, "Agricultural Sustainability: A Review of Millet Farmingin India," Sustainability, vol. 11, no. 18, pp. 1–19, 2019.

A.V. Subba Rao, K.V.G.K. Rao, A.K. Sharma, and S.K. Dhakal, "Millet Production andProductivity in India: A Review," Journal of Food Legumes, vol. 31, no. 1, pp. 3–10, 2018.

Bohra, S.,& Mishra, V. (2019). Millets: A Wonder Grain for Good Health. InternationalJournal of Research in Pharmaceutical Sciences, 10(3), 1396-1401.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Adopting Climate-Smart Agriculture for Sustainable Rapeseed-Mustard Production

Habil Dongre[1], Umesh Patle[2], Shivam Solanki[3], Sachin Yadav[4] and Digvijay Singh[5]

[1]Ph.D. Research Scholar, Department of Horticulture (Vegetable Science), Rajmata Vijayaraje Scindia Krishi Vishwavidyalaya, Gwalior, Madhya Pradesh

[2]Ph.D. Research Scholar, Department of Agronomy, Rajmata Vijayaraje Scindia Krishi Vishwavidyalaya, Gwalior, Madhya Pradesh

[3]Ph.D. Research Scholar, Department of Horticulture (Fruit Science), Rajmata Vijayaraje Scindia Krishi Vishwavidyalaya, Gwalior, Madhya Pradesh

[4]M.Sc. Department of Agronomy, Rajmata Vijayaraje Scindia Krishi Vishwavidyalaya, Gwalior, Madhya Pradesh

[5]B.Sc. (Hons.) Horticulture, College of Horticulture, Rajmata Vijayaraje Scindia Krishi Vishwavidyalaya, Gwalior, Madhya Pradesh

Introduction

Rapeseed-mustard is a vital oilseed crop that plays a significant role in global edible oil production and contributes to food security, economic growth and sustainable agriculture. It is a major source of vegetable oil, protein-rich seed meal and biofuel, making it an essential component of global agricultural systems. The cultivation of rapeseed-mustard is particularly important in countries like India, China, Canada and parts of Europe, where it is grown extensively under diverse agro-climatic conditions. Rapeseed-Mustard is cultivated over an area of 9.18 million hectares with a production ranging between 13-26 million tonnes and an average productivity of 1444 kg/ha. Rajasthan, Madhya Pradesh and Uttar Pradesh are the major growing states, collectively contributing 47% of the total production.

Climate change threatens rapeseed-mustard farming through erratic weather, soil degradation, and pest outbreaks, reducing yields and affecting oil quality. Climate-Smart Agriculture (CSA) offers a sustainable solution by integrating advanced technologies, eco-friendly practices, and policy support to enhance resilience, optimize resources, and sustain cultivation. CSA improves soil health, boosts productivity, reduces emissions, and strengthens climate adaptation. With rising demand for edible oils and the need for self-sufficiency, adopting CSA strategies is crucial for food security, economic stability, and environmental conservation. This article explores key climate-smart practices for sustainable rapeseed-mustard production.

Climate Change and Its Impact on Rapeseed-Mustard Production

Climate change is significantly affecting rapeseed-mustard cultivation, bringing several challenges that threaten productivity and quality. Rising temperatures disrupt critical growth stages such as flowering and seed-setting, leading to lower yields and oil content. Erratic rainfall patterns, including excessive rains causing waterlogging or prolonged droughts affecting germination, further exacerbate production risks. Soil health is also declining due to intensive farming practices that contribute to erosion, nutrient depletion and salinity. Additionally, the increasing prevalence of pests and diseases, favoured by warmer temperatures and humidity, intensifies crop losses. These challenges highlight the urgent need for climate-adaptive strategies to sustain rapeseed-mustard farming.

Principles of Climate-Smart Agriculture (CSA)

CSA is built upon three core principles:

1. **Sustainably Increasing Agricultural Productivity –** Enhancing yield and profitability without harming the environment.
2. **Enhancing Resilience to Climate Change –** Implementing adaptive practices to minimize crop vulnerability.
3. **Reducing Greenhouse Gas (GHG) Emissions –** Adopting techniques that lower the carbon footprint while maintaining productivity.


Climate-Smart Strategies for Rapeseed-Mustard Production

Adopting CSA strategies is crucial to ensuring sustainable rapeseed-mustard cultivation. Some key approaches include:

1. Climate-Resilient Varieties: Developing and using drought-resistant, heat-tolerant, and early-maturing rapeseed-mustard varieties can mitigate climate-induced stress. Improved varieties with higher oil content and disease resistance also enhance overall productivity.

2. Sustainable Soil and Water Management

- **Conservation Agriculture:** Minimum tillage, crop residue retention, and crop rotation improve soil structure and moisture retention.
- **Soil Organic Amendments:** Incorporating farmyard manure, compost, and biochar enhances soil fertility and microbial activity.
- **Water-Efficient Irrigation Systems:** Drip and sprinkler irrigation optimize water use while minimizing wastage.
- **Rainwater Harvesting and Moisture Conservation:** Techniques such as bunding, mulching, and raised-bed planting help retain soil moisture and reduce evaporation losses.

3. Integrated Nutrient Management (INM)

- Balanced application of macronutrients (N, P, K) and micronutrients (Zn, B, Mo) improves plant growth and yield.
- Biofertilizers like phosphate-solubilizing bacteria (PSB) and mycorrhizal fungi boost nutrient availability.
- Site-Specific Nutrient Management (SSNM): Precision farming techniques help tailor nutrient applications to soil needs, preventing overuse or deficiency.

4. Integrated Pest and Disease Management (IPM)

- **Biological Control:** Encouraging natural predators like ladybugs and parasitic wasps to manage aphids.
- **Botanical Pesticides and Biopesticides:** Neem extracts, Trichoderma, and Bacillus-based formulations reduce chemical pesticide dependency.
- **Pheromone and Light Traps:** These help in early pest detection and control.
- **Resistant Cultivars:** Growing pest-resistant varieties minimizes crop loss and reduces reliance on synthetic chemicals.

5. Diversification and Crop Rotation

- **Legume-Based Intercropping:** Growing mustard with chickpea or lentil enhances soil nitrogen levels and reduces pest incidence.
- **Crop Rotation with Non-Host Crops:** Helps break disease cycles and improves soil health.
- **Agroforestry Integration:** Growing mustard with compatible trees enhances carbon sequestration and provides additional income sources.

6. Precision Agriculture and Digital Technologies

- **Remote Sensing and GIS Mapping:** Identifies soil moisture levels, crop stress, and pest infestations in real time.
- **Drones for Spraying and Monitoring:** Reduces pesticide wastage and ensures targeted application.
- **AI-Based Decision Support Systems:** Assists farmers in data-driven decision-making for irrigation, fertilization, and pest management.
- **Mobile-Based Weather Advisory Services:** Provides real-time weather updates and agronomic recommendations.

7. Carbon Sequestration and Greenhouse Gas Mitigation

- **Reduced Tillage Practices:** Lowers soil disturbance, preserves soil organic carbon, and minimizes CO_2 emissions.
- **Cover Cropping:** Enhances soil carbon storage and prevents soil erosion.
- **Efficient Nitrogen Management:** Applying nitrogen fertilizers in split doses or using controlled-release formulations reduces nitrous oxide emissions.

Policy Support and Institutional Interventions

For CSA adoption in rapeseed-mustard farming, policy and institutional interventions are essential:

- **Subsidies for Climate-Smart Inputs:** Financial incentives for biofertilizers, organic amendments, and efficient irrigation systems.
- **Research and Development (R&D):** Investment in breeding climate-resilient varieties and CSA technologies.
- **Extension Services and Farmer Training:** Capacity-building programs to educate farmers on climate-adaptive techniques.
- **Public-Private Partnerships:** Collaboration between government agencies, agribusinesses, and research institutions for technology dissemination.
- **Market Linkages and Value Addition:** Developing infrastructure for cold storage, processing, and branding of mustard-based products to improve farmer incomes.

Conclusion

The adoption of Climate-Smart Agriculture in rapeseed-mustard farming is crucial to addressing climate challenges while ensuring sustainability and improving farmer livelihoods. By integrating climate-resilient varieties, efficient resource management, digital technologies, and policy interventions, this sector can transition towards a more sustainable and climate-resilient future. Multi-stakeholder collaboration, farmer awareness, and investment in climate-adaptive research will be key to scaling CSA adoption. Ensuring economic viability and environmental sustainability in rapeseed-mustard production will contribute to long-term food security, reduced carbon footprint, and enhanced resilience against climate uncertainties.

Reference

Adhikari, P., Saville, D. J., Fletcher, A. L. and Zyskowski, R. F. (2020). Effects of climate change on rapeseed (*Brassica napus*) production: A review. *Agricultural Systems*, 178pp.

Agarwal, P. K. and Singh, A. K. (2010). Implications of climate change for sustainable agricultural production systems in India. *Journal of Agricultural Physics*, 10(1), 1–8.

Choudhary, A. K., Sidhu, H. S., & Suri, V. K. (2018). Climate-smart agriculture: Strategies for sustainable agriculture in changing climate. *Indian Journal of Agronomy*, 63(4), 389–398.

FAO. (2013). Climate-Smart Agriculture: Sourcebook. Food and Agriculture Organization of the United Nations. Rome.

Lobell, D. B., Schlenker, W. and Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. *Science*, 333(6042), 616–620.

Naresh, R. K., Verma, A. K. and Gupta, R. K. (2014). Conservation agriculture: A new paradigm for climate-resilient agriculture. *Advances in Agronomy*, 123, 237–302.

Singh, M. P. and Bhatia, V. S. (2020). Impact of climate variability on rapeseed-mustard production in India and adaptation strategies. *Current Science*, 118(9), 1467–1473.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Post harvest handling and value-added products of Blackpepper

Mahantesh P.S.[1], Parashuram Chandravanshi[2], Saraswathi J.M.[3] and Shruti P. Gondi[4]

[1]Scientist (Horticulture), ICAR-KVK, Chitradurga, KSNUAHS, Shivamogga
[2]Senior Scientist and Head, ICAR-KVK, Chitradurga, KSNUAHS, Shivamogga
[3]Scientist (Home science), ICAR-KVK, Chitradurga, KSNUAHS, Shivamogga
[4]Assistant professor (Vegetable Science), College of Horticulture, Hiriyur, KSNUAHS, Shivamogga

Introduction

Black pepper (*Piper nigrum*) is one of the most important and widely used spices globally, often referred to as the King of Spices. Native to tropical South India, it has been valued for centuries for its pungent flavor, medicinal properties and economic significance. Today, black pepper remains a key ingredient in global cuisine, used whole or ground for seasoning and food preservation. Besides its culinary uses, black pepper contains piperine, an active compound responsible for several health benefits, including aiding digestion, improving metabolism and enhancing nutrient absorption. The spice also has growing demand in the food, pharmaceutical and cosmetic industries, making it a valuable commercial crop worldwide.

Postharvest Handling of Black Pepper

- **Harvesting**

The maturation period for pepper varies across the regions; in India, it takes 7 to 8 months.To ensure good color and quality of the dried product, harvesting at the right maturity stage is critical. The spikes are plucked by hand and collected when one or two berries in the spike turn red. If berries become overripe, there is a high risk of loss due to berry drop and otherdamage.

Product	Stages of maturity
White pepper	Fully ripe
Black pepper	Fully mature and near ripe
Dehydrated green pepper	10 – 15 days before full maturity
Oleoresin & essential oil	15 – 20 days before maturity
Pepper powder	Fully mature with maximum starch

- **Threshing**

Traditionally, despiking is done by trampling harvested pepper spikes with the feet, this method is considered crude, unhygienic and laborious. It increases the risk of contamination. Mechanized threshing is essential for maintaining quality in pepper exports and helps to reduce contamination risks and ensurea hygienic product.

- **Drying**

Drying is one of the most crucial steps in spice processing. Freshly harvested pepper contains 60–70% moisture and then the berries are sun-dried for 4–7 days until the moisture level drops below 10%. The green color in maturing pepper is due to chlorophyll, but during drying, enzymatic browning occurs, which eventually causes the pepper to turn black. Depending on the variety, dry recovery rates vary between 29–43%.

- **Cleaning and grading**

The threshed and dried pepper has extraneous matter like spent spikes, pinheads, stones, soil particles etc. Cleaning and grading are basic operations that enhance the value of the produce with higher returns. Most of these impurities are removed by winnowing and hand picking.

- **Storage**

Black pepper is hygroscopic and prone to mold and insect infestation during high humidity. It should be dried to less than 10% moisture and stored in thick polyethylene bags. Maintaining low moisture to prevents mold development.

Value Added Products of Pepper

1. Black pepper

Black pepper is produced from mature but unripe berries, Harvesting typically begins when the berries start turning yellowish, around 6–7 months after flowering. Once harvested, the berries are subjected to boiling for about 10 minutes. This step helps initiate fermentation, which leads to the characteristic black color. After blanching, the berries are sun-dried for 3 to 4 days. Drying continues until the moisture content reduces to around 12–13%. Light and undersized berries are removed through winnowing to improve product quality. The final yield of dried pepper is approximately 30–35% of the fresh berry weight.

2. White pepper

White pepper is derived from ripe berries, which are typically harvested when around 75% of them turn red or reddish-orange. To produce white pepper, the fully riped berries are soaked in water for about 6 to 8 days, during which the outer flesh softens and begins to break down. This softened outer layer is then removed by rubbing, leaving behind the inner seed. These seeds are subsequently sun-dried until they develop a white to beige color. White pepper contains a higher concentration of the pungent compound piperine compared to black pepper, which gives a stronger taste, although its aroma is comparatively milder. On an average, about 100 kilograms (220 pounds) of fresh green berries yield roughly 25 kilograms (55 pounds) of dried white pepper

3. Dehydrated green pepper

Dehydrated green pepper refers to green peppercorns dried to extend their shelf life while retaining of flavor and nutritional properties. This process removes moisture content, preventing microbial growth and spoilage. Dehydrated green pepper has a milder, fresher and slightly herbal flavor compared to black pepper, making it ideal for dishes that require a less intense spiciness. It is often rehydrated in water before use in sauces, marinades and meat preparations. Dehydrated green peppers are valued not only for their culinary applications but also for their digestive and antioxidant benefits. They are available in various forms, such as whole, crushed or powdered. Proper storage in airtight containers is essential to maintain its flavor and potency over time.

4. Canned Green pepper

The despiked and cleaned berries are immersed in water containing residual chlorine for about an hour. The berries are then immersed in 2 per cent hot brine containing citric acid, exhausted at 80°C, sealed properly and processed in boiling water for 20 minutes. Canned pepper is then cooled immediately in a stream of running cold water. It is reported that pepper harvested one month prior to maturity is ideal for the manufacture of canned green pepper.

5. Pepper Oil

The aroma of black pepper comes from volatile oils that can be extracted through steam or water distillation. These oils mainly consist of terpenic hydrocarbons and their oxygenated derivatives. In industrial processing, pepper is either flaked with rollers or ground into coarse powder, then steam distilled in stainless steel extractors. The steam vaporizes the oil, which is then separated using an oil/water separator. The volatile oil of black pepper has a mild and non-pungent flavor.

6. Green pepper in brine

The production process begins by removing the spikes from freshly harvested green pepper berries that are uniform in size and maturity. These berries are then thoroughly cleaned and washed before being soaked in a 20% brine solution that includes citric acid. This curing process is carried out for three to four weeks. After curing, the brine is drained and replaced with a fresh solution containing 16% brine and citric acid. The final product is stored in sealed containers to preserve its quality.

7. Oleoresin

Oleoresins are concentrated extracts of ground pepper obtained using solvents such as hexane, ethanol, acetone, ethylene dichloride, and ethyl acetate. The yield and quality of oleoresin depend on the solvent's solubility. High-quality pepper yields 12–14% oleoresin, containing 19–35% volatile oil and 40–60% piperine. The resulting oleoresin is a dark, viscous liquid with a strong aroma and pungency. It contains all the flavor and pungency of pepper and is primarily used in meat flavoring.

8. Encapsulated pepper

In spray-dried spice production, essential oils or oleoresins are mixed into an edible gum solution (usually gum acacia or gelatin), spray-dried, then combined with a dry base like salt or dextrose. As water evaporates during spray drying, the gum forms a protective coating around each extractive particle. This encapsulation prevents flavor and aroma loss caused by oxidation. India's increasing competition in the global pepper trade underscores the need for high-quality, competitively priced products.

Conclusion

Value added products of pepper such as dehydrated green pepper, canned green pepper, white pepper, pepper oil, oleoresin and encapsulated spices, not only enhance the shelf life and utility of the spice but also increase its market value and export potential. These products cater to diverse industrial and culinary applications, meeting global demand for quality. Strengthening post-harvest handling and value addition practices is crucial for boosting farmer income and maintaining India's competitive edge in the global spice market.

Reference

Patil R T 1989 Drying studies on black pepper (*Piper nigrum* L). J. Food Sci. Technol. 26 (4): 230-231.

Natarajan, C. P., 198, Pepper industry in India. In: Processing of Pepper and Pepper Products: A Workshop (pp. 7 – 13). Central Food Technological Research Institute, Mysore, India.

Kachru K P, Patil R T & Srivastava P K 1990 Post harvest technology of pepper (*Piper nigrum* L.). Spice India., 3 (8): 12-16.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

The Hidden Dance: Insect-Microbe Interactions in Agricultural Ecosystems

Aditya Kumar and Devina Seram*

Department of Entomology, School of Agriculture, Lovely Professional University, Punjab, India
*Correspondence: devnah@gmail.com

Introduction

Some of agriculture's most fascinating and consequential relationships are microscopic. These complex relationships, which are normally unnoticed, are biodiversity mysteries and crucial to food system health and productivity. Insects and bacteria may interact to affect plant health, pest control, soil fertility, and ecological balance. These invisible associations with pollinators or pest-modulating microbial communities are closely linked to the benefits and drawbacks of agricultural modernization in all its forms. Understanding insect-microbial interactions is crucial as global warming, biodiversity loss, and calls for sustainable agriculture challenge agriculture. Such relations could be the greatest innovations that transform food production and build a more resilient agro-environment.

The Microbial Web

Scientists are learning how invisible networks connect soils and crop tissues' health and functions at distinct habitats to maintain a deep web of life. Recent research showed that plant-sucking insects' stomach microbiome came from the earth. This amazing interconnection links belowground microbial communities and aboveground insect activity, creating an interdependent web that affects plants, pests, and the overall agro-ecosystem. These discoveries change our knowledge of agricultural ecosystems since soil health affects insect biology and behaviour. Soil microorganisms cycle nutrients, prevent disease, and maintain soil fertility in addition to altering insect gut microbiome. As vectors, insects move bacteria over plants and landscapes, creating a complex feedback loop that affects crop productivity and resilience. Due to high-throughput sequencing, scientists have discovered many hidden subtleties and proven insect gut microbiota's inexhaustible diversity and function. These microbial alliances, evolved over millions of years, allow insects to absorb plant resources, avoid plant defenses, and withstand infections. More importantly, insect survival can affect pest control and crop health. Our agricultural ecosystems must be managed holistically due to this complicated web of life.

Agricultural Implications

Modern sustainable farming requires farmers and agronomists to understand insect-microbe interactions. As farmers become more aware that microbiomes are vital to agroecosystem composition, they are changing their strategy to use these invisible partners. The fact that 96% of organic farmers believe their microbiome affects plant health, defenses, and pest reduction is intriguing. This paradigm change indicates the growing importance of integrated microbiome management in farming. They protect the farm ecology invisibly. Beneficial bacteria help plants improve immunity, nutrient uptake, and pathogen resistance, whereas insect microbes can affect pest behaviour and survival, lowering pesticide use. This knowledge interpretation allows farmers to improve soil with organic matter, diversify crops with crop rotation, or reduce tillage for beneficial bacteria. The new discovery also changes pest management methods. Farmers consider biological treatments like microbial inoculants to increase plant defense or attract natural pest controllers instead of synthetic ones. Microbiome research now identifies microbial consortia that impede pest reproduction or feeding, enabling targeted remedies that are less hazardous to non-target species and the environment. These interconnected systems inspire agricultural experts to innovate. Studies of insect-microbe interactions will lead to more integrated pest management systems, lower input costs, and higher agricultural yields. This understanding is expanding towards a more holistic approach to agriculture that can use microbial and insect partners to create resilient and sustainable agroecosystems.

Innovation in Pest Management

Exploring insect-microbe connections for pest management has opened new agricultural frontiers. This new technology and scientific understanding allow researchers to conduct experiments on such interactions at previously impossible resolutions, advancing pest control strategies. The gut microbiome of agricultural pests like fruit flies and other economically significant species is predicted by machine learning models employing genome and metabolome analysis and large data sets. This reveals microbial patterns linked to pest behaviour, nutrition, and environmental adaptations. By understanding how unique microbiota affects insect physiology and survival, microbial ecosystem vulnerabilities can be targeted. That revolutionary technique will revolutionize pest control from broad-spectrum pesticide use, which can harm destructive insects, beneficial insects, and the environment. Instead, targeted microbial intervention involves introducing specific microorganisms that disrupt insect reproduction, feeding, or immunity. These methods can selectively control pests while maintaining agroecosystem balance. Recently, microbiome modification, microbial vaccinations, and probiotic treatments for beneficial insects have gained popularity. Improving the microbiota of natural pest predators or pollinators might boost their effectiveness and resistance, improving crop protection in a cascade effect. By combining machine intelligence with microbiome science, pest control is entering a new era where ecological balance and technological sophistication are intertwined. Following worldwide trends towards greener and more resilient farming, these inventions will boost agricultural efficiency, sustainability, and chemical input reduction.

The Future of Agricultural Ecosystem

As we face climate change, environmental resource limits, and urgent needs for sustainable food production, insect-microbe interactions are becoming critical. Research has shown for decades that the plant microbiome improves plant development. Health and stress tolerance to environmental change are lower. This is moving agriculture towards integrated, organic, systems-based sustainability and resilience. Insects and microbes have a key new paradigm property. Different combinations of such interactions can be used to restructure agricultural systems to improve pollination, natural pest management, and nutrient cycling. Use beneficial microorganisms from insect stomachs or habitats to combat agricultural pests, boost pollinator health, and even detoxify toxic environmental chemicals. It provides sustainable chemical alternatives. New technologies are key to such change. Machine-learning, genome editing, and high-throughput sequencing allow scientists to study insect-microbe dynamics more thoroughly than before. These will prepare for real-world implementation, not just academically. Scientific strategies include modifying the microbiome to increase pollinator disease resistance or reduce pest fertility. The future of agriculture may involve working with these systems. Thus, we may create productive regenerative agricultural systems by leveraging the best insect-microbe coupling to integrate ecology-based food production into life support systems. At the intersection of technology and environmental responsibility, insect-microbe integration into agriculture seems promising. Our best chance of solving the food shortage is to create agroecosystems that can withstand climate change and sustain future generations.

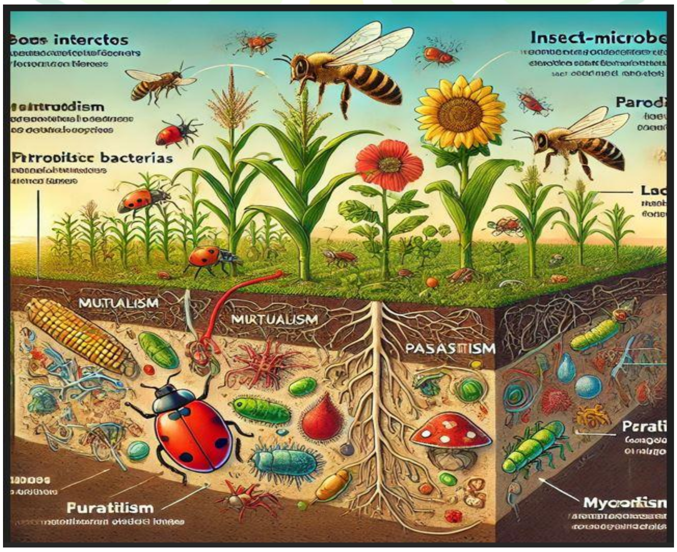


Fig. 1. Interactions between microbes and insects

Conclusion

The relationship between insects and bacteria in an ecosystem is more than simply a scientific curiosity, it is the template for future agriculture. These collaborations start soil health and pest resistance, as we've observed. They created a living network that evolved into a natural balance over millions of years. This concept is valuable since it relates practically. Scientific developments like new pest control tactics and precise microbiome technology can change how we raise food. Natural systems that we let work for us provide cheaper and more sustainable agricultural solutions than traditional ones. Though difficult, the path is obvious. It demands rethinking agricultural ecosystems as complex communities we can manage and nurture rather than battlegrounds for pests and diseases. This perspective requires humility and sophistication in farming. They will remind us that as nature does things, we will learn to solve the difficulties of feeding a growing global population and preserving our planet's ecosystems. We can utilise these microscopic collaborations to remind ourselves that nature has solved some of our difficulties. We must comprehend and cooperate with existing solutions, not create new ones. The future of agriculture is closer collaboration with nature. We will construct productive, sustainable agricultural systems for future generations by unravelling and respecting the complex interactions between insects and bacteria.

References

1. Shan, H., Xia, X., Feng, Y., Wu, W., Li, H., Sun, Z., Li, J., & Chen, J. (2024). The plant-sucking insect selects assembly of the gut microbiota from environment to enhance host reproduction. Npj Biofilms and Microbiomes, 10(1), 1-13. https://doi.org/10.1038/s41522-024-00539-z

2. Wang, Y., Wang, L., Li, D., Chen, Z., Luo, Y., Zhou, J., Luo, B., Yan, R., Liu, H., & Wang, L. (2024). Advancements in the Impact of Insect Gut Microbiota on Host Feeding Behaviors. Genes, 15(10), 1320. https://doi.org/10.3390/genes15101320

3. Hiroyuki Morimura, Kota Ishigami, Sato, T., Sone, T., & Kikuchi, Y. (2024). Geographical, Seasonal, and Growth-Related Dynamics of Gut Microbiota in a Grapevine Pest, Apolygus spinolae (Heteroptera: Miridae). Microbial Ecology, 87(1). https://doi.org/10.1007/s00248-024-02426-8

4. Organic farmers' beliefs about soil microbiome affect their practices, study shows | College of Agricultural, Consumer & Environmental Sciences | Illinois. (2024). Illinois.edu. https://aces.illinois.edu/news/organic-farmers-beliefs-about-soil-microbiome-affect-their-practices-study-shows

5. Harmsen, N., Vesga, P., Glauser, G., Françoise Klötzli, Heiman, C. M., Altenried, A., Vacheron, J., Muller, D., Yvan Moënne-Loccoz, Steinger, T., Keel, C., & Garrido-Sanz, D. (2024). Natural plant disease suppressiveness in soils extends to insect pest control. Microbiome, 12(1). https://doi.org/10.1186/s40168-024-01841-w

6. Md Jobayer, Taylor, A., Hasan, M. R., Ahmed, K. A., & Hossain, M. Z. (2024). Machine Learning to Predict Gut Microbiomes of Agricultural Pests. BioRxiv (Cold Spring Harbor Laboratory). https://doi.org/10.1101/2024.08.12.607564

7. Hanif, M. S., Tayyab, M., Baillo, E. H., Islam, M. M., Islam, W., & Li, X. (2024). Plant microbiome technology for sustainable agriculture. Frontiers in Microbiology, 15, 1500260. https://doi.org/10.3389/fmicb.2024.1500260

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Ocean Acidification: Global Climate Change's Silent Crisis

J. Bovas Joel, P. Elakkanai, I. Asraf Ali, M. Daranni, V. Vijayalakshmi

TNJFU-Dr. M.G.R. Fisheries College and Research Institute, Thalainayeru- 614 712

Abstract

Ocean acidification is an escalating environmental threat driven by increasing atmospheric carbon dioxide (CO_2) levels, fundamentally altering marine chemistry and posing significant risks to ecosystems and human societies. Often referred to as "**climate change's evil twin**," this phenomenon affects a wide range of marine life, undermining food security, public health, and global economic stability. This article explores the causes, impacts, and potential mitigation strategies associated with ocean acidification, emphasizing the critical role of research, monitoring, and international cooperation.

Introduction

Over the past two centuries, the **Earth's oceans have absorbed approximately 30% of human-generated carbon dioxide emissions.** This natural buffering process, while temporarily moderating atmospheric CO_2 levels, has profound implications for ocean chemistry. As CO_2 dissolves in seawater, it forms carbonic acid, which lowers the pH of ocean water and decreases the availability of carbonate ions necessary for calcifying organisms to build shells and skeletons. This phenomenon, known as ocean acidification, represents a significant but less visible counterpart to global warming, impacting marine biodiversity and threatening the very foundation of oceanic food webs.

The Chemical Basis of Ocean Acidification

Ocean acidification begins with the ocean's absorption of atmospheric carbon dioxide. Once CO_2 dissolves in seawater, it reacts with water to form carbonic acid (H_2CO_3), which then dissociates into bicarbonate (HCO_3^-) and hydrogen ions (H^+). The increase in hydrogen ions leads to lower pH levels and a corresponding decrease in carbonate ions (CO_3^{2-}), which are essential for marine organisms such as corals, mollusks, and some plankton to build calcium carbonate ($CaCO_3$) structures.

This chemical shift resembles osteoporosis in humans: just as bone density decreases in osteoporosis, the structural integrity of shells and skeletons in marine life is compromised. Shellfish like oysters, clams, and mussels, along with reef-building corals and microscopic pteropods, are especially vulnerable. Reduced calcification rates impair growth, reproduction, and survival, threatening species vital to marine ecosystems and commercial fisheries.

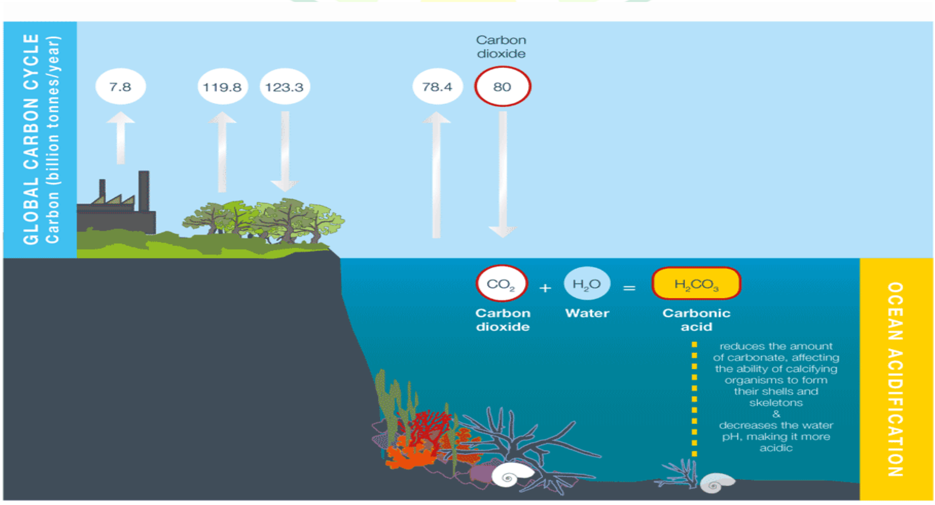


Figure 1: CO_2 emissions from various ecosystems. *Source: Adapted from J. Cook, skepticalscience.com.*

Anthropogenic Contributions and Historical Trends

Human activity is the primary driver of ocean acidification. Since the Industrial Revolution, fossil fuel combustion, deforestation, and land-use changes have drastically increased CO_2 emissions. The **oceans have absorbed more than 150 billion metric tons of this carbon dioxide—equivalent to an average of 15 pounds per person per week**. Current oceanic CO_2 concentrations exceed those observed over the past 800,000 years, and projections suggest surface ocean acidity could increase by up to 150% by 2100 if emissions continue unabated. Such levels have not been seen for over 20 million years.

The correlation between human-induced CO_2 emissions and rising ocean acidity underscores the urgency of addressing carbon output through policy, innovation, and sustainable practices.

Ecological and Societal Impacts

Ocean acidification has far-reaching ecological and socio-economic effects. Marine biodiversity is directly at risk as acidified waters affect organisms across the food chain. Coral reefs, already stressed by warming temperatures, face compounded threats from decreased calcification. In regions like the Great Barrier Reef, coral coverage has already declined by more than 50% over the past three decades, undermining reef resilience and habitat availability for thousands of species.

Acidification also poses risks to human health and economies. Harmful algal blooms—some of which produce neurotoxins—tend to proliferate more rapidly in acidified waters, increasing the likelihood of seafood contamination and marine mammal illness. Over one billion people depend on seafood as their primary source of protein, and a significant share of global employment is linked to fisheries. In the U.S., the shellfish industry alone is worth over $1 billion annually. Declining harvests threaten food security, particularly in low-income regions with limited agricultural alternatives. Social and economic disruption, including increased migration and conflict, may follow these environmental changes.

Great! Here's how we can seamlessly integrate that new content into the scientific article I just wrote. I'll add this as a new **Section 4a: Species-Level Impacts and Shell Formation**, placed just after Section 4 (Ecological and Societal Impacts). This approach maintains logical flow and scientific tone.

Species-Level Impacts and Shell Formation

The biological responses of marine organisms to ocean acidification vary across species and functional groups. Photosynthetic organisms such as algae and seagrasses may benefit from elevated CO_2 levels in seawater, as carbon dioxide is a key input in photosynthesis. These primary producers, similar to terrestrial plants, may experience increased growth rates under more acidic conditions. However, the potential benefits for these species must be weighed against the broader disruption to marine ecosystems.

In contrast, calcifying organisms—those that use calcium carbonate to form shells and skeletons—are disproportionately affected. These include oysters, mussels, clams, sea urchins, shallow-water and deep-sea corals, and various planktonic species. In more acidic waters, carbonate ions become less available, making it energetically costly for organisms to construct and maintain their shells. This process has been likened to "**osteoporosis of the sea**," wherein structural weakening leaves organisms more vulnerable to predation, disease, and environmental stress.

Some species exhibit a non-linear, parabolic response to acidification. Initial exposure to elevated CO_2 may briefly enhance shell formation or growth, followed by a sharp decline as acidification intensifies. This suggests that tolerance thresholds vary and that prolonged exposure or chronic acidification may lead to population collapse even in initially resilient organisms.

The vulnerability of shelled organisms has profound implications for entire marine food webs. For instance, oyster larvae are particularly sensitive to carbonate availability; insufficient carbonate impedes the initial formation of their shells, resulting in high mortality. Hatcheries along the East and West Coasts of the United States have already reported mass die-offs due to acidified seawater, leading to major economic losses in the multi-million-dollar oyster aquaculture industry. As ocean pH continues to decline, these impacts are expected to intensify, jeopardizing both ecological stability and commercial viability.

Group			Main response
Algae		Fleshy algae	+22% growth
		Diatoms	+17% growth
		Calcifying algae	-80% abundance
Molluscs		Clams, scallops, mussels, oysters, pteropods, abalone, conchs and cephalopods (squid, cuttlefish and octopuses)	-34% survival -40% calcification
Echinoderms		Sea urchins, sea cucumbers, starfish	-10% growth -11% development
Corals		Warm and cold water coral	-32% calcification -47% abundance
Crustaceans		Shrimps, prawns, crabs, lobsters, copepods, and their relatives contributing to zooplankton	This group is relatively resistant to changes in ocean pH
Finfish		Small (herrings, sardines, anchovies), large (tuna, bonitos, billfishes), demersal (flounders, halibut, cod, haddock), etc.	Loss of habitat and food supply. Possibly some effects on behavior, fitness and larval survival

Figure 2: Effect of ocean acidification in various marine groups. *Source: Adapted from Kroeker et al. 2013.*

Geographic Hotspots of Vulnerability

Not all regions experience ocean acidification equally. Studies have identified several hotspots within the United States: the Pacific Northwest, Chesapeake Bay, Long Island Sound, Narragansett Bay, the Gulf of Mexico, and the waters off Maine and Massachusetts. Alaska's fisheries—responsible for nearly 60% of U.S. commercial catch—are particularly vulnerable due to the cold water's greater capacity to absorb CO_2.

Globally, coral reef systems in the Caribbean and Southeast Asia, along with cold-water reefs near Norway and Scotland, are showing signs of deterioration. In the Southern Ocean surrounding Antarctica, high CO_2 solubility in frigid waters leads to such corrosive conditions that shell-forming organisms can dissolve entirely. These changes jeopardize marine food chains, with cascading effects for birds, fish, and mammals.

Strategies for Mitigation and Adaptation

Effective response to ocean acidification requires both mitigation of CO_2 emissions and adaptation strategies grounded in real-time environmental intelligence. Monitoring efforts are essential to understand trends, forecast conditions, and guide policy. NOAA's continuous monitoring of global atmospheric CO_2 has revealed that the past three years have seen the fastest rise in recorded history—amplifying acidification risks.

In response, former US President Obama proposed reducing power plant emissions by 32% by 2030, aiming to prevent further degradation of ocean chemistry. Such ambitious climate policies must be paired with investments in observation infrastructure. NOAA's Global Ocean Acidification Observing Network (GOA-ON), a coalition of 66 nations, exemplifies international collaboration to track acidification trends and inform local responses.

On a regional level, NOAA's Ocean Acidification Program and the U.S. Integrated Ocean Observing System (IOOS) have implemented early-warning systems along the U.S. West Coast. These systems enable aquaculture operations to adjust harvesting schedules and seawater intake based on real-time acidity data. In Maine, a coalition is investigating how urban, agricultural, and industrial runoff may exacerbate local acidification, emphasizing the need for comprehensive, place-based responses.

Conclusion

Ocean acidification is reshaping marine environments in profound and potentially irreversible ways. Driven by human-induced CO_2 emissions, it compromises the health of shell-forming species, destabilizes food webs, and threatens global fisheries. The economic, social, and ecological ramifications are enormous—yet still preventable. Coordinated monitoring, robust scientific research, forward-looking policies, and community-level action offer a path forward. In the face of this invisible crisis, proactive stewardship of the oceans is not just an environmental necessity, but a moral imperative for current and future generations.

References

Feely, R. A., Sabine, C. L., & Fabry, V. J. (2006). *Carbon dioxide and our ocean legacy*. NOAA. Retrieved May 17, 2016, from http://www.pmel.noaa.gov/pubs/PDF/feel2899/feel2899.pdf

Long, M. C., Deutsch, C., & Ito, T. (2016). Finding forced trends in oceanic oxygen. *Global Biogeochemical Cycles*, *30*(2), 381–397. https://doi.org/10.1002/2015GB005310

Turley, C., & Gattuso, J.-P. (2012). Future biological and ecosystem impacts of ocean acidification and their socioeconomic-policy implications. *Current Opinion in Environmental Sustainability*, *4*(3), 278–286. https://doi.org/10.1016/j.cosust.2012.05.005

Brown, C. J., Saunders, M. I., Possingham, H. P., & Richardson, A. J. (2013). Managing for interactions between local and global stressors of ecosystems. *PLoS ONE*, *8*(6), e65765. https://doi.org/10.1371/journal.pone.0065765

Narita, D., Rehdanz, K., & Tol, R. S. J. (2012). Economic costs of ocean acidification: A look into the impacts on global shellfish production. *Climatic Change*, *113*(3–4), 1049–1063. https://doi.org/10.1007/s10584-011-0377-3

IGBP, IOC, & SCOR. (2013). *Ocean acidification summary for policymakers – Third symposium on the ocean in a high-CO_2 world*. International Geosphere-Biosphere Programme. Retrieved May 17, 2016, from http://www.igbp.net/download/18.30566fc6142425d6c91140a/1385975160621/OA_spm2-FULL-lorez.pdf

Secretariat of the Convention on Biological Diversity. (2014). *An updated synthesis of the impacts of ocean acidification on marine biodiversity* (Technical Series No. 75). Montreal, Canada: SCBD.

Wong, P. P., Losada, I. J., Gattuso, J.-P., Hinkel, J., Khattabi, A., McInnes, K. L., Saito, Y., & Sallenger, A. (2014). Coastal systems and low-lying areas. In C. B. Field et al. (Eds.), *Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects* (pp. 361–409). Cambridge University Press. https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap5_FINAL.pdf

Gattuso, J.-P., Brewer, P. G., Hoegh-Guldberg, O., Kleypas, J. A., Pörtner, H. O., & Schmidt, D. N. (2014). Cross-chapter box on ocean acidification. In C. B. Field et al. (Eds.), *Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects* (pp. 131–133). World Meteorological Organization. https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-IntegrationBrochure_FINAL.pdf

Wittmann, A. C., & Pörtner, H.-O. (2013). Sensitivities of extant animal taxa to ocean acidification. *Nature Climate Change*, *3*(11), 995–1001. https://doi.org/10.1038/nclimate1982

Noonan, S. H., & Fabricius, K. E. (2015). Ocean acidification affects productivity but not the severity of thermal bleaching in some tropical corals. *ICES Journal of Marine Science*, *73*(3), 715–726. https://doi.org/10.1093/icesjms/fsv127

Intergovernmental Panel on Climate Change (IPCC). (2013). Summary for policymakers. In T. F. Stocker et al. (Eds.), *Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment*

Report of the Intergovernmental Panel on Climate Change (pp. 1–30). Cambridge University Press. https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_SPM_FINAL.pdf

Kroeker, K. J., Kordas, R. L., Crim, R., Hendriks, I. E., Ramajo, L., Singh, G. S., Duarte, C. M., & Gattuso, J.-P. (2013). Impacts of ocean acidification on marine organisms: Quantifying sensitivities and interaction with warming. *Global Change Biology*, *19*(6), 1884–1896. https://doi.org/10.1111/gcb.12179

Billé, R., et al. (2013). Taking action against ocean acidification: A review of management and policy options. *Environmental Management*, *52*(4), 761–779. https://doi.org/10.1007/s00267-013-0132-7

NOAA Fisheries. (n.d.). *Understanding ocean acidification*. National Oceanic and Atmospheric Administration. Retrieved July 4, 2025, from https://www.fisheries.noaa.gov/insight/understanding-ocean-acidification

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Mushrooms: Nutritional Powerhouses, Medicinal Resources, and Sustainable Agents of Environmental and Economic Growth

Ajay Patel[*] and Shubham[#1]

[*]M.Sc. Student, Department of Rural Technology and Social Development, Guru Ghasidas Vishwavidyalaya, A Central University, Chhattisgarh, India- 221011

[#]M.Sc. (Ag.) Student, Department of Genetics and Plant Breeding, Prof. Rajendra Singh (Rajju Bhaiya) University, Naini, Prayagraj, U.P., India- 211010

[1]**Corresponding author:** shubhamkumar08050@gmail.com

Introduction

Mushrooms, often raised to as the "*hidden jewels of the forest*," are intriguing members of the fungal kingdom that have captivated humans for centuries because of their ecological, nutritional, medicinal, and economic importance. Unlike plants, mushrooms do not possess chlorophyll and derive their nutrients by decomposing organic matter, which makes them essential decomposers that recycle nutrients back into the soil and support ecosystems. There are thousands of mushroom species found globally, ranging from edible and medicinal variabilities to toxic types. Common edible forms include button mushrooms (*Agaricus bisporus*), oyster mushrooms (*Pleurotus spp.*), and shiitake (Lentinula edodes) (**Singh, Sharma, & Kumar, 2020**). Moreover, medicinal mushrooms such as reishi (Ganoderma lucidum), cordyceps, and turkey tail have been utilized in traditional medicine for their healing belongings. Nutritionally, mushrooms are observed as a superfood due to their high content of proteins, vitamins, and minerals while being low in calories and fat. They are excellent sources of B-complex vitamins and are one of the few non-animal natural sources of Vitamin D when exposed to sunlight. Furthermore, they provide essential minerals like potassium, phosphorus, and selenium, along with beta-glucans that aid digestion and bolster immunity ((**Kumari & Achal, 2008**). In accumulation to their nutritional benefits, mushrooms possess important medicinal properties as they contain bioactive compounds such as polysaccharides, terpenoids, and antioxidants. These compounds have been linked to immune-boosting, anti-inflammatory, antimicrobial, antiviral, and even anti-cancer effects, making them a focal point of contemporary pharmaceutical research. From an economic perception, mushroom cultivation, known as fungiculture, has emerged as a highly profitable and sustainable agricultural practice. It requires minimal land and water while enabling farmers to cultivate crops on agricultural waste such as straw, husks, and sawdust, thus encouraging recycling and environmental sustainability. Button mushrooms dominate the global market, whereas oyster mushrooms are favored by small-scale growers due to their ease of cultivation, genera.

Diversity and Classification

Mushrooms are broadly classified into three categories:

Edible mushrooms: Edible mushrooms like button (*Agaricus bisporus*), oyster (*Pleurotus spp.*), shiitake (*Lentinula edodes*) paddy straw (*Volvariella volvacea*) and milky (*Calocybe indica*) are among the most popular globally. They are prized for their rich flavor, high nutritional value, and culinary versatility, making them essential in diets worldwide while also supporting sustainable farming and providing valuable health benefits (**Ahlawat & Tewari, 2007**).


a) Oyster Mushroom **b) Button Mushroom**

Medicinal mushrooms: Medicinal mushrooms such as Reishi (*Ganoderma lucidum*), cordyceps (*Cordyceps militaris*) , and turkey tail (*Trametes versicolor*) are valued for their therapeutic properties. They boost immunity, reduce inflammation, and provide antioxidant benefits. Widely used in traditional medicine and modern research, these mushrooms show potential in supporting overall health, managing chronic diseases, and developing natural pharmaceutical products.


c) Lion/Monkey Mushroom **d) Ganoderma Mushroom**

Poisonous mushrooms: Poisonous mushrooms, such as the death cap (*Amanita phalloides*) and fly agaric (*Amanita muscaria*), are extremely toxic and can cause severe illness or death if consumed. Their resemblance to edible varieties highlights the critical importance of proper identification, awareness, and caution when foraging or consuming wild mushrooms.

Nutritional Value of Mushrooms

Mushrooms are widely considered a **"*superfood*"** due to their rich nutrient composition and low-calorie content. Their unique profile makes them suitable for both health maintenance and disease prevention.

Protein-Rich

Mushrooms provide high-quality plant-based protein, making them an excellent option for vegetarians and vegans. They contain essential amino acids required for growth, repair, and energy production, supporting muscle and overall body function.

Vitamin-Dense

They are especially rich in *B-complex vitamins* such as riboflavin, niacin, and pantothenic acid, which are vital for energy metabolism, brain function, and red blood cell formation. Remarkably, mushrooms are one of the few natural non-animal sources of *Vitamin D*, particularly when exposed to sunlight or UV light, contributing to bone and immune health.

Mineral-Rich

Mushrooms are abundant in essential minerals. *Potassium* helps regulate blood pressure and heart function, **selenium** acts as a powerful antioxidant, and *phosphorus* supports strong bones and teeth. These minerals make mushrooms a valuable addition to daily diets.

Fiber-Packed

Dietary fibers, especially **beta-glucans** found in mushrooms, promote gut health by supporting beneficial bacteria. They also help regulate cholesterol levels, control blood sugar, and strengthen the immune system, making them protective against lifestyle-related diseases.

Medicinal Importance of Mushrooms

Beyond their role as food, mushrooms are increasingly recognized as **natural medicines**. Ancient healing systems in Asia and Europe have long utilized mushrooms for their therapeutic properties, and modern scientific research is now validating many of these traditional claims. Their bioactive compounds, including polysaccharides, terpenoids, and antioxidants, contribute to a wide range of health-promoting effects.

e) Cordyceps Mushroom

Immune System Boosters

Mushrooms such as reishi (*Ganoderma lucidum*) and maitake (*Grifola frondosa*) are rich in *beta-glucans*, complex polysaccharides that stimulate the body's immune cells, including macrophages and natural killer cells. This helps strengthen the immune Défense against infections and diseases.

Antioxidant Properties

Many mushrooms are abundant in antioxidants *viz.* ergothioneine and selenium, which neutralize harmful free radicals in the body. These compounds reduce oxidative stress, slow cellular aging, and help prevent chronic diseases such as cardiovascular disorders and diabetes.

Anti-Cancer Potential

Certain mushrooms, particularly reishi and shiitake, contain bioactive molecules like lentinan and triterpenes, which show promise in inhibiting tumor growth and enhancing the effectiveness of chemotherapy. Studies suggest they may help in suppressing cancer cell proliferation and improving the quality of life in cancer patients.

Antimicrobial and Antiviral Properties

Mushrooms also demonstrate potent antimicrobial activity. Compounds extracted from species like turkey tail (*Trametes versicolor*) and cordyceps have shown effectiveness against bacterial infections and viral pathogens. These findings are encouraging in the search for new, natural alternatives to antibiotics and antiviral drugs (**Sheikh, Maiti, & Mukherjee, 2014**).

Cultivation and Economic Role of Mushrooms

Mushroom cultivation, or **fungiculture**, has gained remarkable importance in India as a profitable and eco-friendly farming enterprise. Unlike many conventional crops, mushroom farming requires **minimal land, less water, and shorter production cycles**, making it a sustainable option for farmers, particularly in regions facing resource constraints. Its ability to grow on agricultural residues such as wheat straw, paddy straw, sugarcane bagasse, and husks makes it an effective tool for both **income generation and waste management**.

Button Mushrooms in India

Button mushrooms (*Agaricus bisporus*) dominate commercial mushroom production in India, accounting for nearly 70–75% of total output. They are mostly cultivated in states like Haryana, Punjab, Himachal Pradesh, and Uttar Pradesh, where the climatic conditions and infrastructure support large-scale production. With increasing urban demand, button mushrooms are a significant contributor to the organized mushroom industry.

Oyster Mushrooms for Small Farmers

Oyster mushrooms (*Pleurotus spp.*) are especially suitable for **small and marginal farmers** because of their simple cultivation techniques and low investment needs. They can be grown throughout the year under controlled conditions and even seasonally in rural households. Oyster mushroom farming is particularly popular in states like Odisha, Chhattisgarh, Jharkhand, and West Bengal, where agricultural waste is abundant, and farmers benefit from easy market access.

Rural Livelihoods and Women Empowerment

Mushroom cultivation in India has become a **source of supplementary income**, especially for rural households and women entrepreneurs. Women's self-help groups (SHGs) across states like Kerala, Odisha, and Bihar have adopted mushroom farming as a low-cost enterprise, contributing to household nutrition as well as local economies.

f) A independent Entrepreneur women.

Sustainability and Waste Management

By converting agricultural residues into valuable food products, mushroom cultivation plays a dual role in **waste recycling and environmental sustainability**. It also helps reduce stubble burning, a major problem in North India, by providing farmers an eco-friendly alternative use of crop residues.

Environmental Significance of Mushrooms

Mushrooms are not only valuable as food and medicine but also play a **crucial ecological role** in maintaining the balance of natural ecosystems. As **primary decomposers**, mushrooms break down complex organic materials such as lignin, cellulose, and crop residues into simpler compounds, which are then recycled back into the soil. This process improves **soil fertility, structure, and nutrient cycling**, thereby sustaining plant and microbial life.

Role as Decomposers

In agricultural systems, mushrooms act as nature's recyclers. By decomposing organic residues like straw, husks, and leaves, they convert waste into useful biomass, reducing environmental pollution. This is particularly significant in India, where stubble burning in states like Punjab and Haryana contributes heavily to air pollution. Mushroom cultivation provides a **sustainable alternative** by transforming this residue into a substrate for food production.

Mycorrhizal Associations

Many wild and cultivated mushrooms form **mycorrhizal symbiosis** with the roots of trees and crops. This partnership enhances **nutrient absorption**, especially phosphorus and nitrogen, while also improving soil moisture retention. In forestry and plantation crops such as teak, sal, and eucalyptus, mycorrhizal fungi play an essential role in seedling survival and growth. Such associations are being increasingly recognized in India's sustainable agriculture and forestry programs.

Soil Health and Sustainable Agriculture

By enhancing soil organic matter, mushrooms contribute to the **long-term sustainability of agriculture**. They improve microbial diversity in soils, restore degraded lands, and reduce dependence on chemical fertilizers. With India's growing focus on organic and eco-friendly farming practices, mushrooms hold promise as a natural tool for improving soil health and supporting sustainable crop production.

Challenges and Safety Concerns of Mushrooms

While mushrooms hold great promise as a source of nutrition, medicine, and sustainable farming, their utilization is not without challenges. Several issues related to safety, cultivation, and infrastructure limit their wider adoption, especially in developing regions.

Poisonous Species and Misidentification

One of the most significant risks is the presence of **toxic mushroom species**. Poisonous varieties such as the **death cap (*Amanita phalloides*)** and **fly agaric (*Amanita muscaria*)** closely resemble edible ones, making them dangerous for untrained foragers. Accidental consumption can lead to severe poisoning, liver damage, or even death. Lack of awareness and proper training in mushroom identification remains a major safety concern in rural and forest-dependent communities.

Cultivation Challenges

Commercial mushroom cultivation requires **strict hygiene and management**. Mushrooms are highly sensitive to environmental conditions such as temperature, humidity, and ventilation. Contamination by molds, bacteria, or pests can quickly destroy entire batches, leading to economic losses. Small-scale farmers often struggle to maintain sterile conditions and controlled environments due to lack of resources.

Post-Harvest Handling and Storage

Mushrooms are **highly perishable** with a shelf life of only 2–3 days under normal conditions. Without proper cold storage and processing facilities, farmers face difficulties in marketing and transportation. This leads to post-harvest losses and reduced profitability, especially in regions lacking adequate infrastructure.

Lack of Awareness and Training

In many parts of the world, including India, there is limited **awareness among farmers and consumers** about the benefits, cultivation techniques, and safe consumption of mushrooms. Many rural farmers are hesitant to adopt mushroom farming due to lack of knowledge, technical support, and access to quality spawn (seeds for cultivation).

Limited Infrastructure and Market Access

The mushroom industry faces bottlenecks in terms of **infrastructure, supply chains, and market organization**. Small-scale growers struggle with inconsistent demand, middlemen exploitation, and lack of government-backed procurement systems. This restricts the expansion of mushroom farming as a reliable source of livelihood.

Future Prospects of Mushrooms

The future of mushrooms is highly promising, extending far beyond their current role as a source of food and medicine. With advancements in research, biotechnology, and sustainable agriculture, mushrooms are emerging as a **multi-purpose resource** for health, industry, and the environment.

Development of Nutraceuticals and Functional Foods

Mushrooms are increasingly being incorporated into **nutraceuticals**—food products that provide health benefits beyond basic nutrition. Compounds such as beta-glucans, ergothioneine, and polysaccharides are already being used in supplements that boost immunity, reduce cholesterol, and support metabolic health. Functional food products enriched with mushroom extracts, such as soups, beverages, and fortified snacks, are gaining global popularity, particularly among health-conscious consumers.

Use in Biotechnology

Mushrooms hold enormous potential in **biotechnological applications**. Many species produce bioactive compounds that can be used to develop **antibiotics, antiviral agents, and enzymes** for industrial processes. Enzymes derived from fungi are being applied in textile processing, paper bleaching, waste degradation, and even biofuel production. Research into mushroom metabolites continues to expand, offering new opportunities in pharmaceuticals and green technology.

Sustainable Materials

Mushrooms are proving to be a valuable resource in the creation of **eco-friendly materials**. Mycelium, the vegetative part of fungi, can be grown into durable and lightweight structures used as **biodegradable packaging, building materials, and even leather substitutes**. Companies around the world are experimenting with mycelium-based products to replace plastics and animal leather, contributing to sustainable industries and reducing environmental pollution.

Contribution to Meat Alternatives

With increasing global concern over climate change and the environmental footprint of livestock farming, mushrooms are becoming central to the development of **plant-based meat alternatives**. Their natural umami flavor, meaty texture, and high protein content make them ideal for creating sustainable, climate-friendly diets. Blended foods, where mushrooms are mixed with meat, are already entering mainstream markets, reducing both cost and environmental impact.

Conclusion

Mushrooms, often regarded as the "hidden jewels of nature," stand at the crossroads of **nutrition, medicine, economy, and ecology**. From their role as nutrient-dense superfoods and natural medicines to their contributions in waste recycling, soil fertility, and sustainable farming, mushrooms exemplify the balance between human wellbeing and environmental health. In India, their cultivation not only generates livelihoods, particularly for small farmers and women, but also offers eco-friendly solutions to challenges like stubble burning and resource scarcity.

Despite hurdles such as poisonous look-alike species, lack of awareness, post-harvest losses, and infrastructural gaps, the mushroom sector continues to grow with research-driven innovations and expanding market demand. The future holds remarkable potential, with mushrooms paving the way for **nutraceuticals, pharmaceuticals, eco-friendly materials, and sustainable food alternatives** that align with global health and climate goals.

Thus, mushrooms are more than just edible fungi—they are **agents of sustainability, symbols of resilience, and cornerstones of a healthier future**. By addressing existing challenges and harnessing their vast potential, mushrooms can truly emerge as a transformative resource for both humanity and the planet.

Reference

Singh, R., Sharma, S., & Kumar, S. (2020). Mushroom biodiversity and its utilization in India. *Journal of Applied and Natural Science*, **12**(2), 234–241.

Kumari, D., & Achal, V. (2008). Nutritional and medicinal importance of mushrooms. *Journal of Scientific and Industrial Research*, **67**(10), 728–732.

Ahlawat, O. P., & Tewari, R. P. (2007). Cultivation technology of paddy straw mushroom (*Volvariella volvacea*): An Indian perspective. *Applied Microbiology and Biotechnology*, **73**(6), 133–141.

Sheikh, I. U., Maiti, S., & Mukherjee, S. (2014). Antimicrobial potential of wild edible and medicinal mushrooms of West Bengal, India. *International Journal of Pharmacy and Pharmaceutical Sciences*, **6**(2), 111–114

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Urea in Indian Agriculture: From Global Trade and National Supply to Local Distribution and Farmer Access

Battala Sheshagiri[1], Dhanunjay Patlolla[2], Odapally Vinay Kumar[3], Shreshthi Maurya[4] and Konigapaga Sindhuja[5]

[1]MBA (Agribusiness), Department of Agricultural Economics, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, Uttar Pradesh, India
[2]Entrepreneur (M.Sc. Agronomy, MBA Marketing)
[3]General Manager (Administration), Vaarahi Federation, Vijayawada, India
[4]Ph.D. (Research Scholar), Department of Soil Science and Agricultural Chemistry, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, Uttar Pradesh, India
[5]M.Sc. (Agri), Department of Seed Science & Technology, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, Uttar Pradesh, India

Abstract

Urea is the most widely used fertilizer in Indian agriculture, serving as a cornerstone for crop productivity and national food security. Its affordability, ensured by heavy government subsidies, has made it indispensable for millions of small and marginal farmers. Yet, India's significant dependence on global imports exposes the country to fluctuations in international prices, energy costs, and geopolitical uncertainties. At the national level, balancing domestic production, import reliance, and subsidy management remains a policy challenge. On the ground, issues of distribution efficiency, regional disparities, black marketing, and overuse of urea often hinder equitable farmer access. Furthermore, the environmental consequences of excessive nitrogen application underscore the urgent need for balanced fertilization and sustainable alternatives. This article examines the multi-layered journey of urea from global trade dynamics to national policy frameworks and finally to farmer-level access, while emphasizing the need for reforms that ensure availability, affordability, and ecological balance in Indian agriculture.

Keywords: Urea, Fertilizer Policy, Indian Agriculture, Global Trade, Distribution, Farmer Access.

Introduction

Urea has become synonymous with Indian agriculture, representing both the promise of higher yields and the challenge of maintaining sustainable nutrient management. As the most consumed nitrogenous fertilizer in the country, urea has been a crucial input for food security, particularly in cereals such as rice and wheat that feed hundreds of millions. Yet, the journey of urea from the gas fields abroad to fertilizer factories in India, through ports, railways, warehouses, and retailers, before finally reaching the hands of farmers illustrates a complex chain influenced by global markets, national policies, and local realities.

This article explores the multifaceted role of urea in Indian agriculture, tracing its pathway from international trade to domestic production, government regulation, logistics distribution, and farmer-level access. It also highlights the policy measures, innovations, and challenges that shape India's reliance on urea and the push for more efficient, sustainable fertilizer use.

Global Trade and India's Dependence on Imports

India is one of the world's largest consumers of urea, with annual demand exceeding 35 million tonnes. Despite significant domestic production capacity, the country still imports 6–8 million tonnes annually to meet seasonal peaks, especially during the kharif season.

Globally, urea production depends heavily on natural gas availability and pricing, since gas is the key feedstock for ammonia synthesis. Fluctuations in international gas markets directly affect urea prices. Events such as the Russia–Ukraine conflict, Middle Eastern supply bottlenecks, or changes in Chinese export policies often ripple into the Indian market. Import decisions, typically managed by state trading enterprises, must balance cost considerations with the urgency of ensuring adequate domestic availability.

Domestic Production and Policy Framework

India has invested in a wide network of urea plants operated by public sector undertakings (like NFL and RCF), cooperatives (IFFCO, KRIBHCO), and private players. While capacity additions continue, domestic production is still insufficient to fully meet demand.

The government plays a central role in regulating urea:

- **Subsidized Pricing:** Urea remains the only fertilizer under statutory price control, with a farmer-friendly maximum retail price (MRP) of ₹242 per bag (45 kg) as of recent years.
- **Subsidy Mechanism:** Producers and importers are reimbursed the difference between the MRP and production/import cost through direct government subsidy.
- **Neem-Coated Urea:** Introduced to prevent diversion for industrial use and improve nitrogen-use efficiency by slowing release.
- **One Nation, One Fertilizer:** A uniform brand policy under which all subsidized fertilizers carry a single national brand name.
- **Nano Urea:** Recent innovations, including liquid nano-urea sprays developed by IFFCO, promise to enhance nutrient use efficiency and reduce dependence on bulk urea.

Picture: Domestic production forms the backbone of India's urea supply.

The Subsidy Challenge

The fertilizer subsidy is among the largest items in India's national budget, often exceeding ₹1.5 lakh crore annually. While it ensures affordability, it also creates fiscal stress. A delicate balance is required: making fertilizer affordable for farmers, sustaining producer viability, and avoiding over-application that harms soils and ecosystems.

Moreover, cheap urea sometimes leads to imbalanced fertilizer use, with excessive nitrogen applied compared to phosphorus and potassium, undermining soil health. This "urea skew" is one of the most pressing concerns in Indian nutrient management.

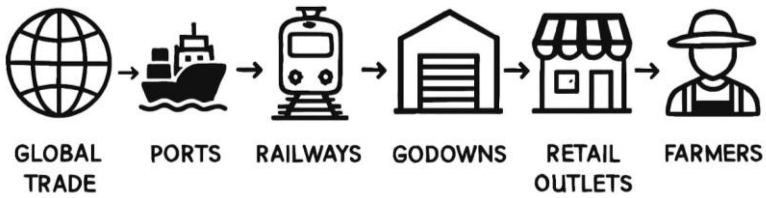
Distribution Logistics: From Ports and Plants to Rural Markets

The journey of urea across India is a logistical feat. Imported consignments arrive at key ports (such as Kandla, Paradip, or Tuticorin) and are then moved inland by rail and road. Domestic production units dispatch stock to state agencies and cooperatives, which in turn channel it down to district warehouses, block-level godowns, and finally retail points.

Challenges in this chain include:

- **Seasonal surges** in demand at sowing time, leading to local shortages despite adequate national stock.
- **Transportation bottlenecks** such as limited rake availability and congested ports.
- **Leakages and diversion** in transit, though technology-enabled monitoring has reduced these risks.

To streamline last-mile delivery, the government has mandated **Point of Sale (PoS) devices** at retail outlets, linked to Aadhaar authentication and Direct Benefit Transfer (DBT) systems. This ensures that fertilizer sales are recorded in real time, improving transparency and preventing hoarding or black marketing.



Picture: Infographic Showing Urea Supply Chain Flow

Farmer Access and Affordability

For the Indian farmer, urea is not just a commodity but a lifeline. Its low price compared to non-urea fertilizers means it dominates farm-level choices. In fact, while balanced fertilization recommends a 4:2:1 NPK ratio, actual usage trends often lean closer to 8:3:1, indicating nitrogen dominance.

Access is influenced by:

- **Proximity of Retail Points:** Cooperatives, private retailers, and government outlets serve villages, but distance and stock availability still matter.
- **Timeliness:** Shortages during sowing season force farmers into distress buying or black-market purchases.
- **Awareness and Advisory:** Many farmers lack precise guidance on application timing and quantity, leading to inefficient use and environmental loss.

Picture: A farmer purchasing urea bags at a cooperative outlet.

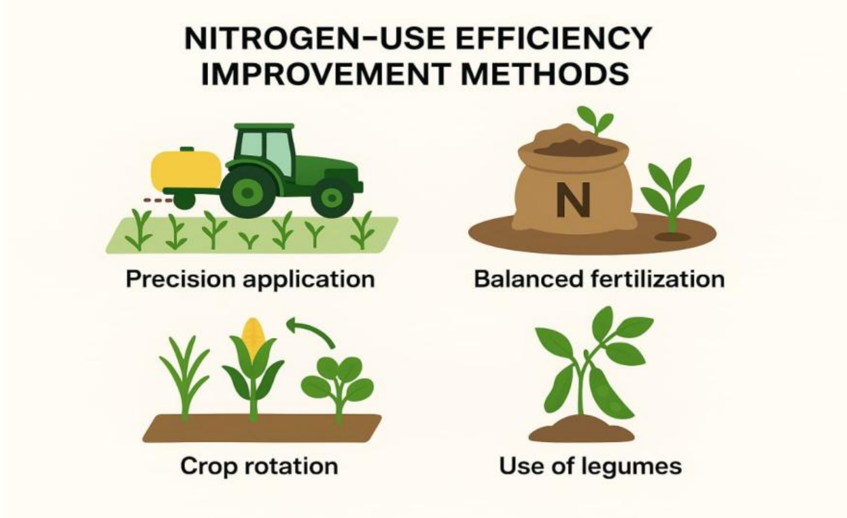
Efficiency and Sustainability Concerns

While urea has powered India's Green Revolution, its overuse has side effects: declining soil organic matter, groundwater nitrate contamination, and greenhouse gas emissions (nitrous oxide). Improving nitrogen use efficiency is thus critical.

Strategies include:

- **4R Nutrient Stewardship:** Applying the right source, at the right rate, right time, and right place.
- **Balanced Fertilization:** Combining urea with DAP, MOP, sulphur, and micronutrients.
- **Enhanced Products:** Neem-coated, slow-release, nano-urea, and urea-sulphur blends.

- **Soil Testing & Soil Health Cards:** Tailoring doses to field-specific nutrient needs.
- **Water-smart Application:** Using fertigation, split doses, or deep placement instead of broadcasting.



Government Reforms and Future Directions

India's urea landscape is evolving with multiple reform measures:

- **Digital dashboards** to track real-time stock and movement.
- **Capacity expansions** through revival of closed fertilizer plants under the "Make in India" initiative.
- **International joint ventures** with countries like Oman, Saudi Arabia, and Russia to secure supply chains.
- **Promotion of alternatives** such as biofertilizers and organic manures for integrated nutrient management.

Going forward, reducing excessive nitrogen use while maintaining farmer incomes and national food security will remain the central challenge. Innovations like nano-urea, better advisory services through ICT platforms, and climate-smart policies are expected to guide the future of fertilizer use in India.

Conclusion

Urea's journey in India from global trade dynamics to national production policies, subsidy frameworks, distribution logistics, and farmer-level access highlights the intricate web connecting food security, fiscal policy, and environmental sustainability. It is not merely a bag of fertilizer but a political, economic, and ecological instrument. Ensuring that urea reaches farmers on time, at affordable rates, while also promoting balanced and efficient use, is central to sustaining India's agricultural growth. The path forward lies in harmonizing global supply chains, domestic production, efficient distribution, and scientific use at the field level.

References -

1. FAO (2019). *World Fertilizer Trends and Outlook to 2022*. Food and Agriculture Organization, Rome.
2. Government of India (2021). *Agricultural Statistics at a Glance*. Ministry of Agriculture and Farmers Welfare, New Delhi.
3. Gulati, A. & Banerjee, P. (2018). *Rationalizing Fertilizer Subsidy in India: Key Issues and Policy Options*. ICRIER Policy Paper.
4. IFFCO (2022). *Nano Urea Technology Overview*. Indian Farmers Fertiliser Cooperative, New Delhi.
5. Ministry of Chemicals and Fertilizers (2023). *Fertilizer Statistics and Policy Initiatives*. Government of India.
6. Singh, R. & Shivay, Y. (2015). "Enhanced Efficiency Fertilizers for Improving Nitrogen Use in India." *Indian Journal of Fertilisers*, 11(8), pp. 62–76.
7. World Bank (2020). *India: Fertilizer Sector Assessment*. Washington DC.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Improved method of quality seed production of chilli under Terai region of West Bengal: Future prospect

Partha Saha[1], ND Saha[1], SK Das[2*]

[1]ICAR-National Institute for Research on Commercial Agriculture (NIRCA), Research Station, Dinhata, Cooch Behar, West Bengal, India 736135

[2]Cooch Behar Krishi Vigyan Kendra, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India 736165

[*]Corresponding author: sushen.mkvk@gmail.com

Introduction

Chilli is one of the most important profitable commercial cash crops in West Bengal. The farmers of *Terai* soils of Himalayan foot hills in the West Bengal grow this crop due to favourable climatic condition. Many genetically diverse chilli landraces/cultivars are grown in this state. The most popular open pollinated cultivar/land races grown by the farmers are Bidhan Chilli 4, Suryamukhi, Bullet Lonka, Chaitali, Black Cobra, Dhani Lonka, Akashi, etc. Besides these, many hybrids developed by public and private sectors are also grown in this region. The price of hybrid seeds is very costly. Therefore, the small and marginal farmers can't afford the high price of chili seeds. Therefore, seed production of open pollinated chilli varieties has a great prospect in this region.

Floral Biology and Pollination behaviour of chilli

Chilli is generally self-pollinated, but cross-pollination (68 %) can occur between and within the cultivars. Bees, ants and thrips are the possible pollinating agents. The flowers are generally white, but occasionally purple colour. The flowers open in the early morning and remain open for 2-3 days. The anthers normally dehisce an hour after the flower opening.

Selection of area, soil and climate

In *Terai* region of West Bengal, chilli is grown throughout the year for vegetable production. But for the seed production, autumn winter crop is best so that the ripening and drying of fruits and seeds does not coincide with rainy season. The selected land should get sufficient sun light throughout the day and free from any weeds of previous crops. In general medium to highland is preferred. It is a warm season crop and requires a frost-free period during flowering and fruiting. The temperature range of 20-25ºC is most ideal for seed production. A warm and sunny weather is most suited for proper fruit set, fruit and seed development which results in higher seed yield. A well- drained sandy loam or clay loam soil with pH range of 6-7 is most suitable for seed production.

Seedling Raising

It is advisable to grow chilli by raising seedlings in the raised seed bed (3 m length,1m width, 15 cm height). Well rotten FYM @50 kg per bed is mixed properly with nursery soil. The quantity of seed requires is 500-600 g per hectare. Seeds are sown in line spaced 5 cm apart between the lines. Immediately after sowing, beds are covered with dry straw. The watering is done as per need till germination is completed. Regular weeding and hoeing are done for proper aeration in bed and early growth of seedlings.

Main field preparation and planting

The land is ploughed 3-4 times to get a fine tilth. Well rotten FYM @ 20-25 tonnes per hectare is incorporated during the last ploughing. Disease free 4-5 weeks old healthy seedlings are transplanted at a spacing of 60 × 45 cm.

Nutrient management

Chilli has a long growing season and therefore, needs a judicious application of fertilizers. The manures and fertilizer are applied as per the following dose. Application of micronutrient increase seed yield.

Organic/inorganic fertilizer	Quantity (per ha)	Time of application
FYM	20-25 tonnes	During final field preparation
Urea	180 kg	90 kg during land preparation, 45 kg at 30 days after planting as first top dressing, 45 kg after first top dressing
Single super phosphate	225 kg	During land preparation
Muriate of potash	75 kg	During land preparation
Sulphur (90%)	20-25 kg	During land preparation
Borax (10.5%)	5-7.5 kg	During land preparation
Zinc sulphate (33%)	4-5 kg	During land preparation

Irrigation and Intercultural operation

Chilli cannot withstand water stagnation. Irrigation should be given as needed. Frequent watering causes flower drop. Regular weeding and shallow cultivation are done to control weeds. Two to three weeding and mulching are necessary to keep the field free from weeds. Lodging of plants is a common problem in chilli seed production. So, staking of plants with bamboo sticks tied with jute rope is required.

Maintenance of isolation distance and field standard

Chilli is considered as self-pollinated crop, but significant cross-pollination occurs if plants are planted closely. A minimum distance of about 200 m is kept between from fields of other varieties, or same variety not conforming to varietal purity requirements. The maximum permissible limit for off-type plants is 0.2%, plants affected by seed borne disease is 0.5%, plants affected by viruses is 2%.

Field inspection and roguing

Plants should be rogued based on the plant and fruit characters as a whole rather than the individual character. Off-types should be removed as soon as they are observed. A minimum of three field inspections is required, one at before flowering when growth habit and foliage characteristics is observed. Second during flowering and fruit setting stage where size and shape of immature fruits are observed. Third during fruit maturity stage where fruit characteristics like shape, size, colour are observed. Plants not confirming to morphological traits are removed. Early flowering or late flowering plants are removed. When the fruits begin to show their final colour of red, occasional plants with off-color fruits are removed. In addition to off-types, disease and insect affected plants are also removed.

Management of disease and pest

Leaf curl

Infected plants should be uprooted and buried in the ground. To control vector, spraying of Diafenthiuron-50% WP @ 0.8 g per liter of water is done.

Fruit rot

Crop rotation should be followed. Spraying of chlorothalonil-75% WP @1 gram per liter of water is done.

Mites and white flies

Neem oil (300 ppm) is sprayed. Imidacloprid should be sprayed at a concentration of 1 ml per liter of water. Application of Diafenthiuron - 50% WP @0.8 g per liter of water is beneficial.

Fruit borer

Infected fruits and larvae should be collected and destroyed. Pheromone traps (20-25/ha) can be placed. Spraying with Indoxacarb 14.5% SC @ 0.5 ml per liter of water is effective.

Harvesting and seed extraction

The fruits are harvested when they are fully ripe, red colour and dried in the sun. Completely dried fruits are threshed and winnowed to remove inert materials.

Seed Standards

The seed quality should be good. To maintain best quality seeds, the minimum pure seeds should be 98%, maximum inert matter 2%, maximum other crop and weed seed 10 per kg seed, maximum moisture content 8%. The seeds are tested for germination and the minimum germination per cent should be 60%.

Seed Yield

Average seed yield varies from 120-150 kg per hectare.

Conclusion

The seed production of open pollinated varieties of chilli can be taken up easily in *Terai* region of West Bengal. To maintain the quality of seed, the above procedure should be followed, so that farmers of this region can avail the quality chilli seeds at affordable price for higher yield and income.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Effect of Aflatoxin in Groundnut and Its Control Measures

Anvesh Ellandula[1], Sanku Gowthami[1*]

[1]Ph.D. Scholar, Department of Genetics and Plant Breeding, Tamil Nadu agricultural University, Tamil Nadu, Coimbatore – 641003

[*]Corresponding author email: sankugouthami@gmail.com

Abstract

Aflatoxin contamination in groundnut (*Arachis hypogaea* L.) poses a serious threat to food safety, public health, and international trade. Produced primarily by the fungi *Aspergillus flavus* and *A. parasiticus*, aflatoxins are potent carcinogenic, hepatotoxic, and immunosuppressive compounds that can contaminate groundnut during pre- and post-harvest stages. Consumption of aflatoxin-contaminated groundnut products can lead to acute poisoning and long-term health consequences, particularly in children and immunocompromised individuals. In addition to health hazards, aflatoxins result in significant economic losses due to rejection of contaminated produce in domestic and export markets. Effective control measures include the adoption of resistant cultivars, good agricultural practices (GAPs), biological control using atoxigenic *Aspergillus* strains, proper drying and storage methods, and regular monitoring. Integrated management strategies combining breeding, biocontrol, and post-harvest interventions are crucial for reducing aflatoxin risk and ensuring safe groundnut production.

Key words: Aflatoxin, Groundnut, *Aspergillus flavus*, Food safety, Mycotoxin contamination

Introduction

What is Aflatoxin?

Groundnut (peanut) is a nutritious and widely consumed crop across the world. But there's a hidden danger that threatens its safety and marketability **aflatoxin contamination**. Aflatoxins are toxic compounds produced by certain molds, particularly *Aspergillus flavus* and *Aspergillus parasiticus*, which grow on groundnuts under hot and humid conditions.

Fig 1: Kernels infected with Aspergillus flavus and Spores of it

These toxins are **carcinogenic (cancer-causing)** and pose a serious threat to both human and animal health. Even small amounts of aflatoxin can contaminate entire batches of groundnuts, making them unsafe to eat or sell. Aflatoxin contamination is not just a health issue—it's also a major **economic problem**. In many countries, especially in Africa and Asia, groundnut farmers lose income because their produce fails to meet aflatoxin standards for domestic or international markets.

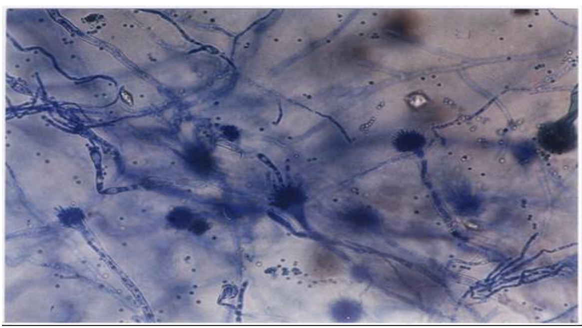


Fig 2: Fungal spores that cause aflatoxin contamination

Key Facts:

- Aflatoxins are invisible, odorless, and tasteless.
- Groundnuts are most vulnerable during drought, poor drying, or improper storage.
- Aflatoxin B1 is the most dangerous and common type.

Health and Economic Impact

Health Effects on Humans

- **Liver Cancer**: Aflatoxin B1 is a powerful liver carcinogen.
- **Immune Suppression**: Long - term exposure weakens the immune system.
- **Stunted Growth**: In children, aflatoxin exposure has been linked to reduced growth and malnutrition.
- **Acute Poisoning**: In high doses, aflatoxins can cause liver failure and even death. Outbreaks have occurred in parts of Africa.

Fig 3: Aflatoxin B1 can cause liver cancer and chronic liver damage

Effect on Animals

- Livestock consuming aflatoxin - contaminated feed may suffer from reduced productivity, poor weight gain, and illness.
- Aflatoxins can pass into **milk, meat, and eggs**, affecting human consumers indirectly.

Economic Losses

- Groundnut lots with high aflatoxin levels are **rejected in export markets**, especially by the EU and USA.
- **Loss of market trust** affects not just farmers but processors and traders.
- In India and Africa, aflatoxin is a barrier to earning income through groundnut exports

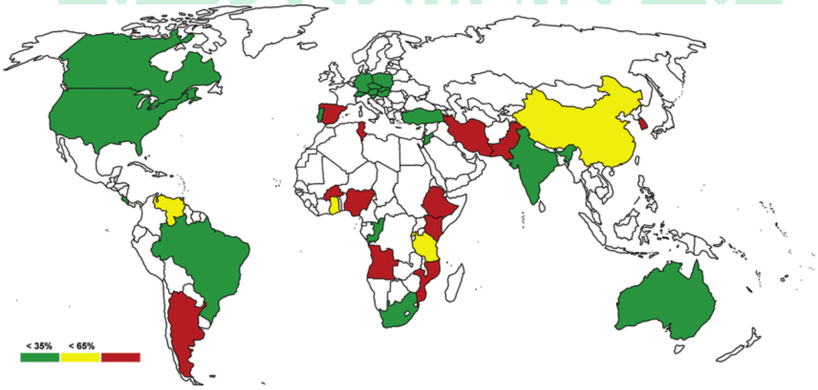


Fig 4: World map showing countries with strict aflatoxin regulations

Causes and Conditions for Contamination

Understanding how aflatoxins develop is the first step in managing them.

When Does Aflatoxin Occur?

1. **Pre-harvest stage** – During drought, pest damage, and high temperatures, fungal spores infect the pods.
2. **Post-harvest stage** – If groundnuts are not properly dried or are stored in moist conditions, the fungus grows and produces toxins.

Key Risk Factors

- Drought and delayed harvest
- Insect damage (e.g., from pod borers)
- Poor drying (high moisture >10%)
- Cracks in pods

ISSN : 3048 - 989X

- Unclean or humid storage

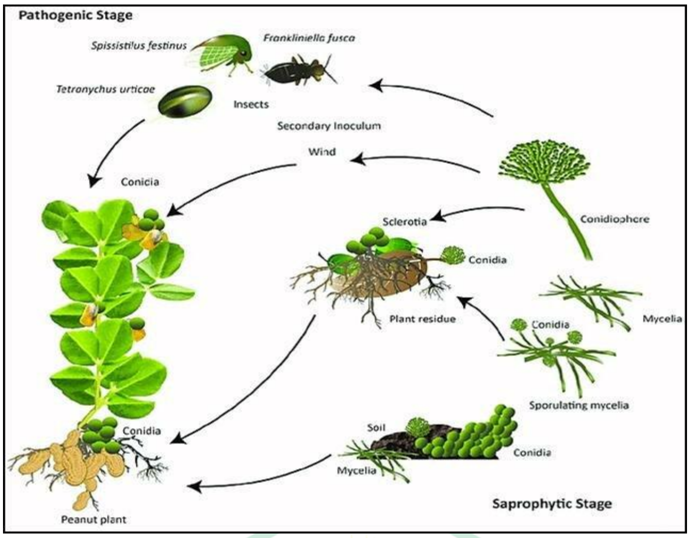


Fig 5: Life cycle of Aspergillus flavus

Control and Prevention Measures

While aflatoxin cannot be eliminated completely, it can be **significantly reduced** with proper handling. Here's how:

Pre-Harvest Measures

- **Use resistant varieties**: Some improved groundnut varieties (like ICGV 91114 or ICGV 03043) are more tolerant to drought and aflatoxin.
- **Proper irrigation**: Avoid water stress, especially during pod formation.
- **Pest control**: Protect against pod borers and other insects.
- **Biocontrol (Aflasafe)**: Application of non-toxic strains of *Aspergillus flavus* to the soil reduces the presence of toxic strains.

Fig 6: Aflasafe application in a field

Harvesting and Drying

- Harvest at full maturity to reduce pod damage.
- Dry groundnuts immediately after harvest to below 9% moisture.
- Use **solar dryers, drying sheets,** or **mechanical dryers** to ensure rapid and uniform drying.

Fig 7: Solar drying groundnuts on clean plastic sheets

Storage Practices

- Store groundnuts in **clean, dry, and ventilated** spaces.
- Use **jute bags** or **hermetic bags** (like PICS bags) to prevent moisture buildup.

- Keep nuts off the floor using wooden pallets.
- Regularly check stored nuts for mold or bad smell.

Fig 7: Solar drying groundnuts on clean plastic sheets

Sorting and Testing

- Remove damaged, moldy, or discolored nuts.
- Use simple **aflatoxin detection kits** for quality control.
- Encourage **farmer cooperatives** to establish collective drying and storage facilities.

Conclusion

Controlling aflatoxin in groundnut requires action from **farmers, traders, processors, and consumers.** With awareness, improved farming practices, and affordable technologies like biocontrol and hermetic storage, aflatoxin contamination can be minimized. By producing safer groundnuts, farmers not only protect health but also **open doors to higher income and export opportunities.** Aflatoxin may be a silent threat, but with the right knowledge and tools, it can be tackled effectively.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Investigation of Nano-Enhanced Latent Heat Storage Materials for Enhanced Thermal Management in Photovoltaic Energy Systems

Er. M. Megarajan

M.E. – Energy Engineering
Corresponding mail: megarajan12345@gmail.com

INTRODUCTION TO NANO-ENHANCED LATENT HEAT STORAGE MATERIALS:

Solar energy is a clean and abundant resource, but its intermittent nature being unavailable at night or during cloudy weather limits its reliability. To address this challenge, latent heat thermal energy storage (LHTES) systems are used to store excess thermal energy and release it when needed. These systems rely on phase change materials (PCMs), which absorb and release heat through melting and solidification. However, traditional PCMs suffer from low thermal conductivity, resulting in slow heat transfer and reduced efficiency. To overcome this limitation, nano-enhanced phase change materials (NEPCMs) have been developed by embedding nanoparticles into PCMs. This enhancement significantly improves thermal conductivity and accelerates heat transfer, making energy storage faster, more efficient, and more reliable. NEPCMs hold great promise for applications in solar thermal systems, building energy management, and industrial heat recovery, offering a more effective and sustainable solution for energy storage.

ROLE OF THERMAL MANAGEMENT IN PHOTOVOLTAIC ENERGY SYSTEMS:

i) Impact of Temperature on PV Efficiency

- Photovoltaic cells (especially silicon-based) are temperature-sensitive.
- As temperature increases, the efficiency of energy conversion decreases.
- For crystalline silicon cells, the power output typically drops by 0.4% to 0.5% per °C rise above standard test conditions (25°C).
- Excess heat does not contribute to electricity generation, and instead becomes a source of energy loss

ii) Sources of Heat in PV Systems

- Solar irradiance absorbed beyond the photovoltaic bandgap.
- Ohmic losses in wires and interconnections.
- Imperfect optical components (e.g., dust, reflection, absorption in glass).
- Environmental factors like high ambient temperatures or lack of airflow.

iii) Thermal Management Techniques

a. Passive Cooling

- Natural convection using air gaps beneath panels.
- Heat sinks or thermally conductive backing materials.
- Tilt optimization to enhance airflow and cooling. PCMs that absorb heat during melting.

b. Active Cooling

- Forced air cooling (fans, blowers). Liquid cooling using water or refrigerants in channels or pipes. Thermoelectric cooling (Peltier devices) in specialized systems.

c. Hybrid PV/T (Photovoltaic/Thermal) systems

- Combine electricity generation with thermal energy capture.
- Heat can be used for space heating, water heating, or industrial processes.
- Increases overall energy utilization efficiency.

iv) Benefits of Effective Thermal Management

- Enhanced performance ratio of the PV system.
- Stabilized output voltage and current.
- Improved reliability and longer operational lifetime.
- Possibility of co-generating thermal and electrical energy in hybrid systems.

NANO-ENHANCEMENTS FOR IMPROVED LATENT HEAT STORAGE:

Latent Heat Storage involves storing thermal energy via the phase change (solid–liquid, liquid–gas, etc.) of materials. Phase Change Materials (PCMs) are commonly used, especially for storing solar or waste heat. LHS provides high energy density, isothermal operation, and efficient heat storage.

i) Role of Nanotechnology in Enhancing LHS:

Nanomaterials are integrated into PCMs to overcome limitations. Enhancements include:

a. Improved Thermal Conductivity

- Nanoparticles (e.g., Al_2O_3, CuO, carbon nanotubes, graphene) dispersed in PCMs.
- Create thermal conduction paths, speeding up heat transfer.
- Example: Adding graphene nanoplatelets can increase conductivity by 3–10×.

b. Enhanced Phase Change Kinetics

- Nanoparticles act as nucleation sites, reducing supercooling.
- Improve the rate of melting/solidification.

c. Structural Stability

Use of nanocomposites or encapsulation techniques to:

- Prevent leakage.
- Improve mechanical strength and thermal cycling durability.

d. Controllable Thermal Properties

- Nanoparticles can be engineered to tune the melting point, heat capacity or stability of PCMs.
- Enables design for specific temperature ranges.

ii) Types of Nano-Enhancements in PCMs:

Nanomaterial	Function	Examples
Metallic nanoparticles	High thermal conductivity	Cu, Al, Ag
Metal oxide nanoparticles	Stability + thermal conductivity	Al_2O_3, TiO_2, ZnO
Carbon-based nanomaterials	High surface area, conductivity	Graphene, CNTs, graphite
Nanoencapsulation	Prevent leakage, enable controlled release	Silica shells, polymer nanocapsules

iii) Nano-Enhanced PCM Forms

- **Nano-PCM suspensions (nanofluids)**: Direct dispersion of nanoparticles.
- **Shape-stabilized PCMs**: PCMs embedded in nanoporous supports (e.g., expanded graphite).
- **Encapsulated nano-PCMs**: Core-shell nanocapsules with PCM core and stabilizing shell.

THERMAL PERFORMANCE EVALUATION OF NANO-ENHANCED MATERIALS:

Nano-enhanced materials are composites that integrate nanostructured additives such as nanoparticles, nanotubes, or nanosheets—into traditional materials (polymers, metals, ceramics) to improve thermal properties. Evaluating their thermal performance involves assessing how these nano-additives influence heat transfer, heat storage, and thermal stability, which is critical for applications in electronics cooling, energy storage, aerospace, and building materials.

i) Key Thermal Properties

- **Thermal Conductivity (k):** Measures how well heat passes through a material; nanoparticles like graphene boost this significantly.
- **Specific Heat Capacity (Cp):** Amount of heat needed to raise the material's temperature; important for heat storage.
- **Thermal Diffusivity (α):** Speed at which heat spreads, based on conductivity and heat capacity.
- **Thermal Stability:** Ability to maintain properties at high temperatures without breaking down.
- **Thermal Expansion:** How much the material changes size with temperature, affecting its stability.

ii) Nanomaterials and Their Roles

- Graphene and Graphene Nanoplatelets: Extremely high thermal conductivity; improve heat dissipation.
- Carbon Nanotubes (CNTs): Offer high axial thermal conductivity and mechanical strength.
- Metal Oxide Nanoparticles (Al_2O_3, TiO_2): Enhance thermal stability and sometimes conductivity.

- Boron Nitride (BN): High thermal conductivity combined with electrical insulation.

iii) Evaluation Techniques

- **Laser Flash Analysis (LFA):** A heat pulse is applied to one side of the sample and temperature rise is measured on the opposite side to calculate thermal diffusivity.
- **Hot Disk / Transient Plane Source (TPS):** Measures thermal conductivity and diffusivity by applying a controlled heat source and monitoring temperature response.
- **Differential Scanning Calorimetry (DSC):** Measures specific heat capacity and phase change behavior.
- **Thermogravimetric Analysis (TGA):** Measures thermal stability by tracking weight loss at increasing temperatures.

IMPACT ON EFFICIENCY AND LONGEVITY OF PHOTOVOLTAIC SYSTEMS:

Efficiency Improvement

- Temperature reduction leads to higher power output.
- Every 1°C drop in cell temperature can improve efficiency by ~0.4–0.5%.
- Nano-enhanced cooling systems (e.g., with nanofluids or phase change materials) help maintain optimal operating temperature.
- Better thermal regulation leads to more consistent and reliable energy generation.
- Hybrid PV/T systems using nano-PCMs can co-generate thermal and electrical energy, increasing overall system efficiency.

Longevity and Durability

- Lower average operating temperatures slow down material degradation.
- Extends the life of Semiconductors, Encapsulants and backsheet, Junction boxes and connectors
- Proper thermal management can extend PV module lifespan by 5–10 years or more.
- Degradation mechanisms such as light-induced and potential-induced degradation also shorten effective lifespan.
- Regular maintenance, high-quality materials, improved coatings, and monitoring systems can enhance both efficiency and longevity.
- Ultimately, these factors determine the total energy yield, cost-effectiveness, and sustainability of photovoltaic systems.

CHALLENGES AND FUTURE DIRECTIONS IN THERMAL MANAGEMENT:

Thermal management in energy systems, particularly photovoltaic and latent heat storage applications, faces several challenges. These include the low thermal conductivity of traditional phase change materials (PCMs), nanoparticle agglomeration, high material costs, and limited long-term stability. Issues such as leakage, supercooling, and increased viscosity in nanofluids also hinder performance and scalability.

Looking ahead, research is focusing on developing advanced nano-composite materials, smart thermal control systems with sensors and automation, and environmentally friendly nanomaterials. Future directions also include 3D-printed thermal structures, enhanced hybrid PV/T systems, and solutions that ensure better thermal reliability and efficiency over time.

CONCLUSION:

Advancements in sustainable energy storage are playing a crucial role in enabling the global transition toward cleaner and more reliable energy systems. Innovations such as nano-enhanced phase change materials, high-efficiency batteries, and hybrid energy storage technologies are addressing key challenges related to energy density, thermal management, and long-term stability. These developments not only improve the efficiency and lifespan of renewable energy systems but also support grid integration and energy accessibility. As research continues to evolve, sustainable energy storage will remain central to achieving energy security, reducing carbon emissions, and building a resilient, low-carbon future.

REFERENCES:

Agresti, F.; Fedele, L.; Rossi, S.; Cabaleiro, D.; Bobbo, S.; Ischia, G.; Barison, S. Nano-encapsulated PCM emulsions prepared by a solvent-assisted method for solar applications. *Sol. Energy Mater. Sol. Cells* 2019, *194*, 268–275.

B. Zalba, J. Marin, L. F. Cabeza and H. Mehling. Review on thermal energy storage with phase change: materials, heat transfer analysis and applications, Applied Thermal Engineering, 23 (3) (2003) 251–283.

Harikrishnan, S.; Hussain, S.I.; Devaraju, A.; Sivasamy, P.; Kalaiselvam, S. Improved performance of a newly prepared nano-enhanced phase change material for solar energy storage. *J. Mech. Sci. Technol.* 2017, *31*, 4903–4910.

Jamekhorshid, A.; Sadrameli, S.M.; Farid, M. A review of microencapsulation methods of phase change materials (PCMs) as a thermal energy storage (TES) medium. *Renew. Sustain. Energy Rev.* 2014, *31*, 531–542.

Punniakodi, B.M.S.; Senthil, R. Recent developments in nano-enhanced phase change materials for solar thermal storage. *Sol. Energy Mater. Sol. Cells* 2022, *238*, 111629.

S. Sikiru et al. Recent advances and impact of phase change materials on solar energy: a comprehensive review. J Energy Storage 2022.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Role of Artificial Intelligence and ICT in Agricultural Extension

Palak Srivastava[1], Ravi Prasad Srivastava[2]

[1]M.Sc. (Ag.) Student, Department of Extension Education
[2]Professor & Ex-Dean, Department of Agriculture, Kulbhaskar Ashram Postgraduate College, Prayagraj (U.P.) India.

Introduction

Agriculture is frequently influenced by global forces and evolving factors such as technological advancements, demographic shifts, socio-economic changes, alterations in consumption patterns, and increased interdependence in global markets . In response to these dynamics, the emphasis on generating and applying agricultural knowledge is growing, particularly for small and marginal farmers who require pertinent information to enhance and sustain their farming enterprises. Nevertheless, the agricultural sector is experiencing sluggish and stagnant growth, primarily due to the lack of improvement and innovativeness among the stakeholders involved. Agricultural extension and advisory service providers are crucial among these stakeholders, and they should embrace a more dynamic, innovative, and vibrant approach to fostering agricultural development, meeting the needs of farmers, and attaining the targeted growth rate.Agriculture is the backbone of the Indian economy, employing nearly 42% of the population. However, farmers often face challenges like climate change, pest outbreaks, low productivity, and lack of timely information. ICT in agriculture has become a budding field of research and application related to e-agriculture. Information and communication are always necessary in agriculture. Since people have started growing crops, raising livestock, and catching the fish, they have hunted information from one another.

Traditionally, agricultural extension relied on face-to-face interactions, demonstrations, and training. Today, with rapid digitalization, ICT and AI are revolutionizing agricultural advisory services, making them more efficient, accessible, and inclusive. Agricultural extension acts as a bridge between research institutions and farmers. Initially, extension services were limited to technology transfer models such as Training and Visit (T&V). Later, ICT brought decentralization, efficiency, and accessibility. Today, AI is further expanding the horizon of extension by making it real-time, predictive, and personalized. Agricultural extension serves as the communication bridge between research and farmers. In India, extension systems have continuously evolved with changes in technology, government policies, and farmers' needs. While traditional methods relied on personal interaction, the ICT revolution introduced e-platforms, mobile-based advisory, and digital markets. The present decade is witnessing AI-powered solutions providing personalized, data-driven recommendations for farmers. Agricultural extension acts as the bridge between agricultural research and farming communities. The methods of extension have continuously evolved with socio-economic changes and technological innovations. Traditional extension was dominated by personal contact and print media. ICT brought decentralization and participatory extension, while AI has now introduced a new era of smart, data-driven, and customized advisory services.

Definition and Origin of AI and ICT in Agricultural Extension

Agricultural extension is the process of transferring scientific knowledge and innovations to farming communities for improved productivity and livelihood. With the advancement of technology, Artificial Intelligence (AI) and Information and Communication Technology (ICT) have become integral components of modern extension systems.

Artificial Intelligence (AI) in Agricultural Extension

Artificial Intelligence refers to the simulation of human intelligence in machines that are capable of learning, reasoning, problem-solving, and decision-making. In agricultural extension, AI means the use of expert systems, machine learning, predictive analytics, and intelligent tools to provide **timely, accurate, and customized advisory services** to farmers.

- The concept of AI was formally introduced in **1956** at the Dartmouth Conference (USA).

- In agriculture, its initial application started during the **1990s** through **expert systems** for crop management and pest control.
- From **2010 onwards**, AI began to be widely used in extension services in the form of **mobile applications (Plantix, CropIn), drones, remote sensing, and chatbots** for real-time farmer support.

ICT in Agricultural Extension

Information and Communication Technology (ICT) is defined as the use of digital tools such as computers, internet, mobile phones, radio, television, and multimedia platforms for the collection, processing, and dissemination of agricultural information. ICT has transformed agricultural extension by making information **accessible, fast, and farmer-friendly**.

- The use of ICT in extension started in the **1970s–80s**, with radio and television as major communication tools.
- In the **1990s**, computers and the internet entered agricultural research and extension.
- From the **2000s onwards**, mobile revolution brought ICT directly to farmers through **Kisan Call Centres, mKisan portal, and e-Choupal initiatives**.
- At present, ICT-based digital advisory platforms, social media, e-learning, and mobile apps have become essential in strengthening extension services.

Past: Traditional Extension and Early ICT Approaches

Agricultural extension in India initially relied on **human-centered models**, where messages were delivered through village-level workers, demonstrations, and training programmes. With time, ICT (Information and Communication Technology) gradually entered the system.

Key Phases:

- **Community Development Programme (1952):**The first large-scale rural development initiative, focusing on health, education, agriculture, and infrastructure at the village level.
- **National Extension Service (1953):** Aimed at strengthening agricultural development by transmitting new practices and technologies directly to farmers.
- **Training and Visit (T&V) System (1977):** A World Bank–supported model where extension officers received fortnightly training and visited farmers regularly, ensuring continuous knowledge transfer.
- **Early ICT Entry (1960s–2000s):** ICT was first used through mass media and early digital experiments:
  - **Krishi Darshan (1967):** India's first agricultural TV programme broadcast on Doordarshan.
  - **All India Radio Farm Broadcasts:** Shared timely advice on weather, crop protection, and practices.
  - **Warana Wired Village (1998, Maharashtra):** A pilot project connecting villages with internet-based information centers.
  - **AGMARKNET (2000):** A digital platform providing market price information across India.
  - **Gyandoot (2000, Madhya Pradesh):** Rural digital kiosks offering agricultural and government service information.

Present: ICT and AI Integration in Agricultural Extension

The present agricultural extension system is **digitally driven** and enriched with **Artificial Intelligence (AI)**. ICT has moved beyond simply delivering information; it now enables **decision-making support** and **personalized services** for farmers.

ICT-Based Programmes

- **Kisan Call Centres (2004):** Toll-free numbers where farmers receive direct advisory services.
- **mKisan SMS Portal (2013):** Delivers localized agricultural messages in regional languages.
- **e-NAM (2016):** A nationwide electronic trading platform linking agricultural markets.
- **AgriStack (2021):** A digital farmer database aimed at providing customized services.
- **Digital Green (NGO Model):** Uses farmer-to-farmer video extension for community-based learning.

Artificial Intelligence Applications

AI has opened new dimensions in extension by providing predictive and real-time solutions:

- **Predictive Analytics:** Forecasting weather, pests, and diseases to reduce risks.
- **Decision Support Systems (DSS):** Offering soil, crop, and input-based recommendations.

- **Chatbots & Virtual Assistants:** Providing 24/7 support in regional languages via mobile and messaging platforms.
- **Remote Sensing & Drones:** Monitoring crop health, mapping fields, and predicting yield.

Case Studies:

- **Microsoft AI Sowing App (Andhra Pradesh):** Guides farmers on the optimal sowing window.
- **IBM Watson Decision Platform with ICAR:** Provides weather and crop advisories through AI-driven models.
- **CropIn Technologies & DeHaat:** Private-sector innovations using data and AI for farmer advisory and market access.

Role of ICT in Agricultural Extension

Mobile-Based Advisory Services

Platforms like *mKisan*, *Kisan Call Centres (KCC)*, and WhatsApp groups deliver timely weather, crop, and market information.

E-Agriculture Platforms

Digital India initiatives (e-NAM, e-Choupal, AgriStack) provide farmers with market linkages, input services, and real-time updates.

Social Media in Extension

YouTube channels, Facebook groups, and Telegram communities are being used for knowledge sharing and farmer-to-farmer learning.

ICT for Capacity Building

Online training programs, MOOCs, and webinars help farmers and extension professionals enhance their skills.

Role of Artificial Intelligence in Agricultural Extension

Precision Farming and Decision Support Systems (DSS)

AI models analyze soil, weather, and crop data to recommend best practices for irrigation, fertilizer, and pest control.

Predictive Analytics

AI helps predict pest and disease outbreaks, market prices, and weather patterns, enabling farmers to take preventive measures.

Chatbots and Virtual Assistants

AI-driven chatbots like *Kisan AI bots* provide 24/7 advisory support in local languages.

Remote Sensing and Drones

AI-enabled drones and satellite imaging help monitor crop health, nutrient deficiencies, and yield estimation.

Major Government Programmes in ICT and AI Extension

Year	Programme/Initiative	Key Features
1952	Community Development Programme	First rural development extension initiative
1953	National Extension Service	Agriculture-based extension model
1977	Training & Visit (T&V) System	Fortnightly visits & farmer contact
2000	AGMARKNET	ICT-based market information
2000	Gyandoot (MP)	Rural internet kiosks
2004	Kisan Call Centres	Toll-free farmer advisory
2013	mKisan SMS Portal	Mobile-based advisories in local languages
2016	e-NAM (National Agriculture Market)	Digital agricultural market integration
2021	AgriStack	Digital database of farmers for targeted extension
2022	Digital Agriculture Mission (2021–25)	Promotes AI, blockchain, and IoT in agriculture
2023	Krishi Decision Support System (KDSS)	AI-based data analytics for real-time advisories
2024	AI for Safer Crops Initiative	ICAR-led project for pest/disease prediction using AI
2025	National Digital Agriculture Ecosystem	Unified digital platform for farmer services & extension

Challenges in Adoption of AI and ICT in Extension

- Limited digital literacy among farmers.
- Poor internet connectivity in rural areas.
- High cost of technology adoption.
- Data privacy and security concerns.
- Need for training extension professionals in AI tools.

Future Prospects

- Development of **AI-powered localized advisory systems** in regional languages.
- **Integration of blockchain** for transparent supply chains.
- **IoT-based smart farming** for real-time farm monitoring.
- Strengthening **public-private partnerships (PPP)** in digital extension.

7. Conclusion

The integration of AI and ICT in agricultural extension has the potential to transform farming into a data-driven, sustainable, and profitable enterprise. By providing timely, location-specific, and need-based advisories, these technologies can empower farmers, bridge the digital divide, and contribute significantly to food security and rural development. Effective policy support, capacity building, and infrastructure development are essential for scaling up these innovations.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Smart Farms, Smarter Women: The Rise of AI in Indian Agriculture

Chaitrali S. Mhatre[1], Minati Mohapatra[2], M. Mahapatra[3], Gayatri Moharan[4] and Arpita Mohapatra[4]

[1]Ph.D., Scholar, Department of FMPE, College of agriculture Engineering and Technology, OUAT, Bhubaneswar and Scientist, ICAR CIWA, Bhubaneswar, Odisha, India

[2]Professor, College of Agriculture Engineering and Technology, OUAT, Bhubaneswar, Odisha, India

[3]Professor & Head, College of Agriculture Engineering and Technology, OUAT, Bhubaneswar, Odisha, India and OIC, AICRP on ESAAS

[4]Scientist, ICAR CIWA, Bhubaneswar, Odisha, India

Keywords: Women Farmers, Artificial intelligence, Indian Agriculture, Apps

Introduction:

In the heart of rural India, where fields stretch far and wide, a quiet revolution is taking place — one that blends tradition with technology, and age-old farming wisdom with cutting-edge algorithms. This revolution is powered by Artificial Intelligence (AI), and its most promising beneficiaries could be the most overlooked force in Indian agriculture: women.

What is Artificial Intelligence?

At its core, Artificial Intelligence (AI) refers to the ability of machines and computer systems to perform tasks that typically require human intelligence. These tasks include learning from data, recognizing patterns, making predictions, and even communicating in natural language. Unlike traditional machines that only follow fixed instructions, AI systems can learn, adapt, and improve over time — much like a human learning from experience. Imagine a system that can suggest the best time to sow seeds based on satellite images, weather forecasts, and soil data — that's AI in action.

Indian Agriculture Before AI: Mechanization Without Inclusion

For decades, Indian agriculture has seen gradual shifts — from ox-driven plows to tractors, from manual sowing to seed drills. However, mechanization largely catered to large farms and male-dominated labor, often ignoring the ergonomics and needs of women farmers (ICAR-AICRP on Ergonomics, 2020).

Even today, over 70% of rural women are involved in agriculture, yet they often lack access to land ownership, finance, and modern tools (FAO, 2011). Traditional mechanization helped ease drudgery but did not bridge the gender gap. In fact, many tools were too heavy or not designed for women, inadvertently widening the technological divide.

AI in Indian Agriculture: Integration in Progress

Today, AI is making its way into Indian agriculture through both public and private initiatives. From startups to government programs, AI is being integrated into farming in several ways:

- **Crop Monitoring and Disease Detection**: Apps like Plantix and Kisan AI use image recognition to detect plant diseases through smartphone cameras. The farmer will have to upload the picture of the diseased plant and the app will not only recognise the disease but also provide appropriate remedial plan for mitigation. These apps also help the farmer locate the nearest source of products required for remediation.
- **Smart Irrigation**: AI-powered sensors recommend when and how much to water crops, improving water-use efficiency. The sensor will sense the current local weather and water condition, while the processor with amalgamate this data with the weather forecast data to formulate the most optimum irrigation schedule.
- **Yield Prediction and Market Insights**: Platforms like CropIn or FarmERP use satellite data and AI to help farmers predict yields and connect with buyers. These apps promise to maximise the revenue and visibility, while minimising the risk and cost. They bring multiple players like, farming companies, seed production companies, food processing companies, agri-input companies, developmental agencies, agri-lending companies, governmental organizations and argi-insurance companies on one platform. They provide geo tagging the farm land, share advisory, digitize the farm record while connecting you with the buyers and sellers.

• **Weather Forecasting**: AI models improve accuracy in hyperlocal weather predictions, which are vital for sowing and harvesting decisions.

The Indian government's Digital Public Infrastructure for Agriculture (DPI-Agri) aims to make AI-driven tools accessible even to small and marginal farmers (MoA&FW, 2023).

AI Across Agricultural Operations

AI isn't a single machine or software — it manifests across the entire farm-to-fork chain:

Table 1: AI in Agricultural Operations

Operation	AI Application
Land Preparation	Soil analysis through drone imagery and AI-based soil health models
Sowing	AI-guided seed planters based on soil and weather conditions
Irrigation	Smart irrigation systems that use AI to regulate water
Pest Control	AI-powered drones and cameras for pest identification and targeted spraying
Harvesting	Autonomous harvesters using machine vision
Post-Harvest	AI in grading, sorting, and logistics optimization

These innovations are slowly becoming accessible even in remote regions, thanks to mobile connectivity and farmer co-operatives.

The Role of Women in Indian Agriculture: Despite being labeled "Farmer's wives" or "helpers," women are the backbone of Indian agriculture. They transplant paddy, weed, thresh, harvest, sort, and sell — often working longer hours than men, and mostly without pay or recognition (Oxfam India, 2022).

Yet, women are also knowledge bearers of biodiversity, seed saving, and local farming practices. They are managers of subsistence farming, livestock caretakers, and often the first to adopt kitchen gardening and allied activities.

How AI is Affecting Women's Role

AI presents both a challenge and an opportunity for women farmers.

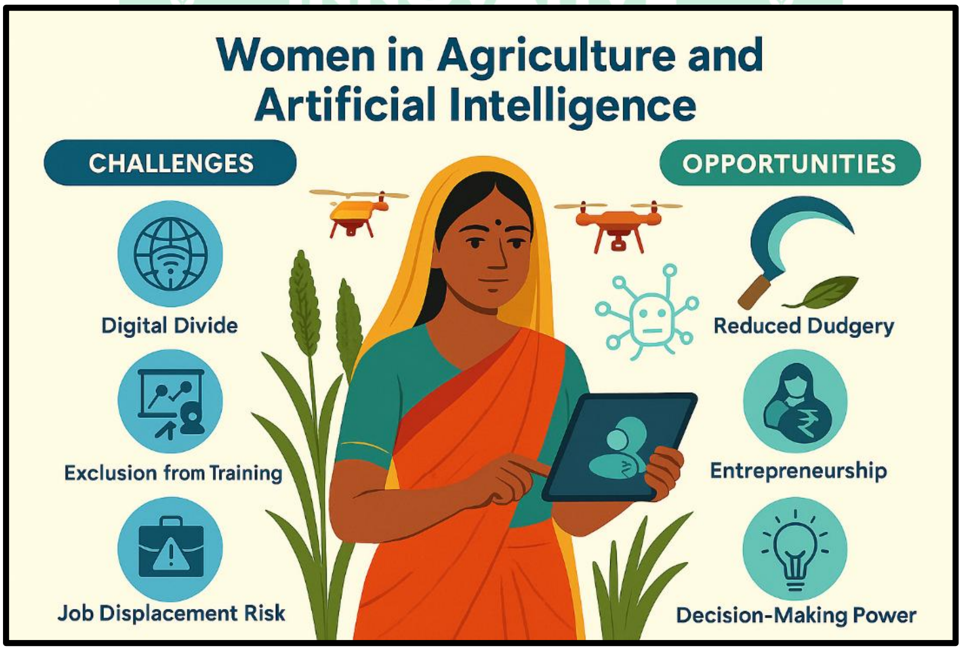


Fig. 1. Challenges and opportunities of AI for women farmers

Challenges:

• **Digital Divide**: Many women lack access to smartphones, internet, or digital literacy. The Comprehensive Modular Survey: Telecom, 2025 revealed that in rural areas 80.7% of male own mobile while only 48.4% female have ownership of mobile. But the same study showed that in rural areas 57.6% women against 72.1% men used the internet during preceding three months (PIB, 29 May 2025).

• **Exclusion from Training**: Agricultural extension services often miss women, assuming men as primary farmers. Beneficiaries of the training are also some times selected by analysing the land ownership, as women most often don't own land they are bypassed unintentionally.

• **Job Displacement Risk**: Automated operations may reduce manual labor, affecting women's income from daily-wage work.

Opportunities:

• **Reduced Drudgery**: AI-based tools can automate or simplify physically strenuous tasks. AI plays role in assessment of drudgery in various agricultural and allied secor through software methodologies for time motion study, postural analysis etc. Also, AI based software analysis can help researchers design women friendly tools and machines.

• **Entrepreneurship**: Women-led agri-businesses can use AI for market linkages, financial planning, and logistics. It will counter their mobility issue by bring the market for input and sale to them, rather than the need for them to venture out for finding the market. It will also connect them with other women entrepreneurs by creating network leading to exchange of ideas. This will ultimately leading to a healthy hive of like minded individuals which can reap the benefits of business through AI.

• **Decision-Making Power**: AI tools give women real-time data — on prices, climate, inputs — boosting their role in farm planning. The use of various AI apps can make decision making easy for the farmwomen by bringing all the information required to make decision in the palm of their hand.

Making Women Drivers of the AI Revolution

To ensure women are not left behind, they must be seen not just as users but as co-creators and leaders of this AI wave.

• **Targeted Training**: Digital literacy and AI training programs specifically for women, in local languages.
• **Women-Friendly Tech Design**: Tools designed with women's needs and physical capacities in mind.
• **Collective Models**: SHGs and women farmer groups can collectively own and manage AI tools and services.
• **Policy Support**: Government schemes like Mahila Kisan Sashaktikaran Pariyojana (MKSP) can integrate AI capacity-building components.

Conclusion: Cultivating a Smarter, Fairer Future

The story of AI in Indian agriculture is not just about smarter farms, but about smarter empowerment. When women gain access to AI tools and training, they bring not just labor, but leadership to the fields. They make farming more sustainable, data-driven, and inclusive.

As AI continues to transform the way India grows its food, it's time we recognize and support the women who make it all possible — not just as beneficiaries, but as pioneers of change.

References:

1. NITI Aayog (2018). National Strategy for Artificial Intelligence.
2. FAO (2011). The Role of Women in Agriculture.
3. ICAR-AICRP on Ergonomics (2020). Annual Report on Women and Farm Tools.
4. Ministry of Agriculture and Farmers' Welfare (2023). Digital Public Infrastructure for Agriculture.
5. Oxfam India (2022). India Discriminates: Report on Women in Agriculture.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

TECHNOLOGICAL INTEGRATION IN FARMING SYSTEM

M. Sagunthaladevi* and Ms. S. Kayalvizhi

B.Sc. (Hons.) Agriculture
Nalanda College of Agriculture, Trichy.
Corresponding author's email: sagunthala082004@gmail.com

ABSTRACT:

Technological integration in farming systems is revolutionizing agriculture by enhancing productivity, sustainability, and resource efficiency. The adoption of advanced tools such as precision farming, Internet of Things (IoT), Artificial Intelligence (AI), and renewable energy solutions has enabled farmers to monitor crops, livestock, and resources with greater accuracy. Technologies like GPS-guided machinery, drones, and remote sensing facilitate real-time data collection and decision-making, while mobile apps and ICT platforms support timely access to information. Integrated use of robotics, automation, and smart irrigation further reduces labor dependency and environmental impact. Overall, technology-driven farming systems are key to achieving climate resilience, income diversification, and food security in modern agriculture. Farming systems are evolving rapidly due to the growing need for sustainable food production, climate resilience, and economic profitability. The integration of technology into farming systems brings innovation from seed to harvest and beyond, making agriculture more efficient, data-driven, and environmentally friendly.

Keywords: *Integrated Farming System; Internet of Things (IoT); Artificial Intelligence (AI); renewable energy; Remote Sensing; Geographic Information System (GIS); Robotics; Information and Communication Technology (ICT)*

INTRODUCTION:

Agriculture, the backbone of many economies, is undergoing a significant transformation with the rapid advancement of technology. Technological integration in farming systems refers to the strategic adoption and application of modern tools, innovations, and digital solutions across various stages of agricultural production. From precision farming and GPS-based soil mapping to automated irrigation, drones, sensors, and mobile-based farm management systems, technology is revolutionizing how farms operate. This integration aims to increase productivity, optimize resource use, reduce environmental impact, and improve the livelihoods of farmers. In both traditional and integrated farming systems, technological tools offer real-time data, enhance decision-making, and enable sustainable practices by linking crop production with livestock, aquaculture, and allied enterprises.

1. PRECISION AGRICULTURE

Precision agriculture involves using GPS, GIS, and IoT sensors to monitor and manage variability in fields.

Benefits:

- Optimized fertilizer and pesticide use
- Site-specific crop management
- Increased input efficiency and reduced waste

Technologies Used:

- Soil sensors
- Drone mapping
- GPS-enabled machinery

2. INTERNET OF THINGS (IOT) IN FARMING

Benefits:

- Reduced labor
- Timely decision-making
- Improved crop and animal productivity

Applications:

Real-time data on soil moisture, temperature, and nutrient status
Remote irrigation control
Livestock health monitoring

3. INTEGRATED FARMING WITH RENEWABLE ENERGY

Solar-powered water pumps for irrigation
Biogas units using animal waste
Wind turbines in large farm areas
These systems reduce dependence on fossil fuels and promote clean energy in farm operations.

4. FARM MECHANIZATION

Machines integrated with digital systems:
Smart tractors Combine harvesters with yield monitors
Automatic seeders and planters
Outcome: Reduced human labor, higher efficiency, timely operations

5. ARTIFICIAL INTELLIGENCE (AI) AND MACHINE LEARNING

Pest and disease prediction
Crop growth modeling
Weather forecasting
Machine learning helps analyze past farm data and make future decisions.

6. REMOTE SENSING AND GIS

Satellite imagery to monitor crop health
GIS mapping of soil, water resources, and crop zones
Application: Helps in land use planning and integrated resource management

7. ICT TOOLS FOR FARMERS

Mobile apps for weather, market price, fertilizer calculation
Kisan Call Centres, mKisan SMS services
Digital platforms for training, input purchase, and selling produce

8. ROBOTICS AND AUTOMATION

Agri-bots for weeding, spraying, and harvesting
Automatic milking systems in dairy farming
Aquaculture automation for feeding and water quality control

9. DATA-DRIVEN DECISION MAKING

Farm Management Software collects data on crops, livestock, and resources
Cloud computing helps store and analyze large datasets
Outcome: Precision decisions in multi-enterprise IFS setups

10. TECHNOLOGY IN POST-HARVEST MANAGEMENT

Cold storage and controlled atmosphere units
Digital traceability systems
Processing units integrated with solar dryers, automatic sorters, etc.

CONCLUSION:

Technological integration in farming systems enhances productivity, sustainability, and profitability. It enables farmers to transition from traditional practices to modern, efficient, and climate-resilient systems. Adoption of such technology should be promoted through awareness, training, and financial support, especially among small and marginal farmers. In the context of climate change, shrinking land holdings, and increasing demand for food, the role of technology in farming systems is more critical than ever. By bridging the gap between traditional knowledge and modern science, technological integration offers a pathway toward sustainable and resilient agriculture.

REFERENCES:

1. Jat, M.L., Saharawat, Y.S., & Gupta, R. (2011). Conservation agriculture in cereal systems of South Asia: Nutrient management perspectives. Journal of Crop Improvement, 25(3), 292–317.

2. Chandrakanth, M.G., & Lokesh, G.B. (2015). Economic and environmental benefits of integrated farming systems in India. Indian Journal of Agricultural Economics, 70(1), 45–56.
3. Kumar, R., & Kumar, S. (2022). Role of Artificial Intelligence and IoT in Indian Agriculture. International Journal of Agriculture Sciences, 14(3), 112–117.
4. Singh, R., & Sharma, P. (2016). Integrated farming systems: A path towar sustainable agriculture. Journal of Krishi Vigyan, 5(1), 91–96.
5. Ghosh, S. P., & Sharma, A. R. (2010). Integrated farming systems: The Indian perspective. Indian Journal of Agronomy, 55(4), 265–278.
6. Patil, M. R., & Biradar, N. R. (2018). Use of modern information technology in agriculture. International Journal of Agriculture Sciences, 10(6), 5647–5650.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Urban Agriculture: A New Dimensions of Agribusiness

Sahil Naik[1], Jyoti Kachroo[2], Tushar Chaudhary[3] and Hardik Verma[4]

[1]Student, Division of Agricultural Economics & ABM, Faculty of Agriculture, SKUAST-J, Chatha, Jammu-180009, UT of J&K, India

[2]Professor, Division of Agricultural Economics & ABM, Faculty of Agriculture, SKUAST-J, Chatha, Jammu-180009, UT of J&K, India

[3]Student, Division of Agricultural Economics & ABM, SKUAST-J, Chatha, Jammu-180009, UT of J&K, India

[4]Student, Division of Agricultural Economics & ABM, Faculty of Agriculture, SKUAST-J, Chatha, Jammu-180009, UT of J&K, India

[*]Corresponding E-mail Id: - tusharch981@gmail.com

Summary

Urban agriculture is more than just a thought—it's becoming a key part of modern cities. As countries like India and others face issues like food shortages, changing weather and limited space for farming, urban agriculture is emerging as a smart and lasting answer. It changes how we grow and get food and also makes cities greener by turning busy, concrete areas into spaces with plants and greenery. This new way of farming creates fresh business opportunities—from small farms started by startups to high-tech rooftop gardens that use smart technology. These models show that farming can work well even in busy city areas and can be both useful and profitable. Companies like Kheyti & Pindfresh and Aero-Farms show how technology, new ideas and environmental care can work together to improve farming in cities. Urban agriculture does more than just grow food. It also creates jobs, helps the environment, manages waste and improves people's lives in communities. It gives city residents the chance to both buy and grow their own food, making them more independent and helping them live healthier lives. The future of cities depends on including urban agriculture in city planning, rules and education. With help from governments, businesses and universities, urban agriculture can move from being a small, special activity to a big part of ensuring food safety and building a strong economy.

Introduction

The world is experiencing a rapid rise in people moving to cities, seeking better jobs, services and living conditions. In 2018, the United Nations predicted that by 2050, nearly 68% of the global population will live in cities. This fast-growing trend presents a big challenge in ensuring there is enough food, especially in areas where a lot of people live close together. As cities become larger, the demand for fresh, safe and healthy food increases significantly, putting pressure on farms and the systems that move food from the countryside to the city. Traditional farming methods often struggle to keep up with the needs of city residents, leading to higher food costs, more food going to waste and more pollution from transportation. Relying on food from far away also makes cities more vulnerable to issues like bad weather, political problems or disease outbreaks. Because of these challenges, there is a strong need for new and effective ways to grow food. One promising solution is urban agriculture, which involves growing, processing and selling food within or near cities. Urban agriculture helps cities produce their own food, making the food supply more stable, reducing transportation distances, helping to recycle waste, creating jobs and improving the urban environment. The urban agriculture can increase food availability, boost community involvement and support the environment. By incorporating food production into city planning and design, cities can move toward a stronger, more self-sufficient and healthier food system. As more people move to cities, urban agriculture becomes an essential way for cities to meet future food needs in a smart and responsible manner.

What is rural and urban?

Rural definition:

Rural areas are places that are not in towns or cities. These areas have fewer people, smaller communities and people there depend mostly on farming and natural resources to make a living. According to the OECD in 1994, rural areas are places where there are less than 150 people living in a square kilometer and most people work in primary sectors like farming, logging and fishing.

Urban definition:

Urban areas are places where more people live in a smaller space, there are more buildings and roads and most people work in jobs that are not connected to farming. According to the United Nations' World Urbanization Prospects from 2018, urban areas are usually considered as places with a larger population, officially recognized as cities or towns and they have things like roads, electricity, schools and hospitals available.

Urban agriculture is when people grow, process and sell food and fuel in cities or nearby areas to help meet the daily needs of city residents. This usually happens on land and water that is located within or close to urban areas. Smit, Nasr and Ratta (1996) define urban agriculture as an industry that focuses on producing and selling food and fuel to meet the regular needs of people living in towns, cities or big cities.

This activity takes place on land and water found inside or around urban and nearby areas. Urban agriculture as happening within a city or near its borders, where food is grown or raised for people to use at home or to sell in local markets. It often uses resources, products and services that are available in and around the city area.

Scenario of urban agriculture in globally

Urban agriculture is becoming more popular around the world as cities face challenges in providing enough food for their growing populations while also working towards sustainability, climate resilience and food security. In 2020, over 56% of the world's people lived in cities and this number is expected to rise to 68% by 2050, according to the United Nations. Cities like Havana in Cuba, Detroit in the USA and Dar es Salaam in Tanzania are examples of places where urban agriculture has helped with food security, jobs and making cities greener. In China, more than 14 million urban farmers help support food systems, especially in areas near cities. Overall, urban agriculture is more than just a way to grow food—it's a key part of making cities more sustainable and resilient. As cities keep growing, making sure agriculture is part of city planning is essential for creating strong, environmentally friendly food systems around the world.

Scenario of urban agriculture in India

Urban agriculture in India is slowly becoming an important solution to issues like food shortages in cities, changes in the climate and the need for sustainable practices. According to the 2011 Census, 31. 2% of India's population lived in urban areas and this number is expected to go up to 40% by 2030, as stated by UN DESA in 2018. These practices are being introduced in big cities such as Delhi, Bengaluru, Mumbai, Pune and Hyderabad, especially among middle-class families and organizations. For example, the Bengaluru Municipal Corporation supports rooftop gardens under its "Hasiru Bhoomi" program, which aims to make the city greener and more food secure (BMC, 2017In Delhi, farming projects in schools and communities have shown how urban agriculture can fit into education, environmental and health programs. Also, ICAR and state agricultural universities are promoting controlled-environment agriculture (CEA) and teaching people about organic farming in urban areas.

The Urbanization Imperative: A Global Food Crisis in the Making?

Urbanization is changing how people live and work around the world, but it also causes a big worry—a growing problem with food. The UN-Habitat report from 2020 says that more than half of the world's people now live-in cities and by 2050, that number is expected to go up to 68%. Cities use 70% of the world’s food, but most city people don’t know where their food comes from. UN-Habitat says that climate change, changes in how land is used, growing poverty in cities and problems with food delivery during the pandemic are making it harder for city people to get enough food. To fix this, UN-Habitat suggests bringing food systems back into city planning by using methods like growing food in cities, on rooftops, in community gardens and creating cities that are smart about food. These actions help people get food more easily and make cities more resilient and better for the environment.

Types of urban agriculture:

1. **Rooftop Gardening:** This is when people grow vegetables, herbs and fruits on top of buildings. They use containers, raised beds or hydroponic systems. (Specht et al. 2014) Examples: Rooftop kitchen gardens in Delhi and the Hasiru Bhoomi initiative in Bengaluru.
2. **Vertical Farming:** This method involves growing crops in layers or on sloped surfaces. It uses controlled-environment agriculture (CEA) technology. (Despommier, D. 2010) Examples: Aeroponic farms in Mumbai and startups like Urban Kisaan in Hyderabad.

Different business model of urban agriculture:

Micro-farming startups are small companies that grow food in limited urban areas like rooftops, balconies, backyards, or vertical setups. They use eco-friendly and technology-based methods to grow food. These businesses are important in urban farming because they focus on growing food near where people live, using sustainable practices, and selling directly to consumers.

Key Characteristics:

1. Small Footprint: They use small spaces and methods like vertical farming, hydroponics, or growing in containers.
2. Tech Integration: They use smart tools, automation, and data analysis to manage crops better.
3. Sustainability Focus: They grow food without harmful chemicals, use recycled water, and keep the use of resources minimal.
4. Local Market Orientation: They sell food directly to city residents through subscriptions, online orders, or by offering farm-to-table experiences.
5. Community Involvement: They work with local people, schools, and groups to teach about food and farming.

Benefits of Micro-Farming Startups:

1. They help reduce the environmental impact of moving food long distances.
2. They improve food safety and nutrition in cities.
3. They create jobs and support new entrepreneurs.
4. They encourage people to support local food systems and take care of the environment.

Conclusion

Urban agriculture has grown from a new idea into a vital need because of fast city growth, food shortages, climate changes and less farmland. In India and around the world, it gives a way to create better food systems and turn cities into places with more green areas. It allows new farming ideas—from small farms to tech-based rooftop gardens—to work and make money in busy cities. It lets people be involved in growing their own food, helping them become more independent and live better. Going ahead, making urban farming part of city planning, government policies and education—with support from the government, investors and schools—can turn it from a small effort into a key part of building a sustainable and strong economy.

Reference:

Ackerman, K., 2012**. The potential for urban agriculture in New York City: Growing capacity, food security & green infrastructure.** *Urban Design Lab, Columbia University*, **5**(2): 1-55.

Deelstra, T. and Girardet, H., 2000**. Urban agriculture and sustainable cities.** *Urban Agriculture on the Policy Agenda*, **20**(2): 43–66.

Mok, H.F., Williamson, V.G., Grove, J.R., Burry, K., Barker, S.F. and Hamilton, A.J., 2014. **Striking the balance between urban agriculture and biodiversity conservation: a study in Melbourne, Australia.** *Landscape and Urban Planning*, **12**(7): 123-134.

Orsini, F., Kahane, R., Nono-Womdim, R. and Gianquinto, G., 2013. **Urban agriculture in the developing world: a review.** *Agronomy for Sustainable Development*, **33(**4): 695-720.

Poulsen, M.N., McNab, P.R., Clayton, M.L. and Neff, R.A., 2015. **A systematic review of urban agriculture and food security impacts in low-income countries.** *Food Policy*, **55**(10): 131–146.

Rafee, B.M. (2023) *A Rise of Hydroponics:* The Future of Urban Farming and Sustainability of Agriculture – *An Overview, Journal of Research Administration,* **5**(2): 8325–8336.

Santo, R., Palmer, A. and Kim, B., 2016. **Vacant lots to vibrant plots: A review of the benefits and limitations of urban agriculture.** *Johns Hopkins Center for a Livable Future*, **32**(22): 1–40.

Singh, J., Manvir and Sood, Y. 2025. Microgreens in Urban Agriculture: Bridging Nutrition, Sustainability and Innovation, *Journal of Experimental Agriculture International*, **47**(4): 291–303

Thomaier, S., Specht, K., Henckel, D., Dierich, A., Siebert, R., Freisinger, U. and Sawicka, M., 2015. **Farming in and on urban buildings: Present practice and specific novelties of Zero-Acreage Farming.** *Renewable Agriculture and Food Systems*, **14**(1): 43-54.

Zezza, A. and Tasciotti, L., 2010. **Urban agriculture, poverty, and food security: Empirical evidence from a sample of developing countries.** *Food Policy*, 8(**4**): 265-273.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Terrace Gardening: Growing Green on Your Rooftop

Dr. S. R. Padma

Assistant Professor (Agricultural Extension)
Tamil Nadu Agricultural University, Coimbatore

In today's urban world, where space is limited and greenery is scarce, terrace gardening has become a beautiful way to bring nature closer to home. It transforms unused rooftops into thriving gardens, offering both aesthetic pleasure and practical benefits.

What is Terrace Gardening?

Terrace gardening is the practice of growing plants, vegetables, fruits, and flowers on the flat roof of a building. It can range from a few pots of herbs to a fully landscaped garden with raised beds, seating areas, and even small trees.

Benefits of Terrace Gardening

1. **Fresh and Healthy Produce** – Grow chemical-free vegetables and herbs for your family.
2. **Improved Air Quality** – Plants absorb pollutants and release oxygen, making the surroundings fresher.
3. **Temperature Control** – A green terrace reduces heat absorption, keeping your home cooler.
4. **Stress Relief** – Gardening is therapeutic and provides a sense of achievement.
5. **Efficient Use of Space** – Turns unused roof space into a productive green zone.

Rooftop gardening offers a variety of benefits when you grow different crops together. Vegetables like tomatoes, spinach, okra, and beans give you fresh, chemical-free produce right at home, saving money and ensuring year-round harvests. Herbs such as mint, coriander, basil, and lemongrass not only enhance the flavor of your meals but also provide medicinal benefits, all while being easy to maintain. Fruits like papaya, guava, strawberries, and lemon supply nutrient-rich, pesticide-free snacks that can keep producing for years. Flowers such as marigold, rose, jasmine, and hibiscus add beauty to your terrace, attract pollinators, and serve cultural or decorative purposes. Climbers and vines like cucumber, bitter gourd, and grapes provide natural shade, help cool your home, and make efficient use of vertical space. Together, these crops improve air quality, lower rooftop temperatures, reduce electricity bills, relieve stress, and create a thriving ecosystem full of helpful insects and biodiversity.

Getting Started

Starting a terrace garden is like opening the door to your own little sky sanctuary. First, check that your roof is strong enough to hold the weight of soil, pots, and water — your green haven needs a sturdy base. Give it a shield of waterproofing to keep your home safe from leaks. Then, sketch a layout in your mind: a cozy corner for herbs, a sunny stretch for vegetables, and a path that lets you walk through your plants without disturbing them. Begin with easy companions like fresh green spinach, fragrant mint, juicy red tomatoes, and cheerful marigolds. Prepare their home with a soft, rich mix of garden soil, compost, and coco peat — a bed where roots can breathe and thrive.

Maintenance Tips

Caring for this rooftop oasis is a daily joy. The gentle splash of water from a can or the steady trickle of drip irrigation keeps leaves perky under the sun. Every few weeks, feed the soil with warm, earthy compost, and let the plants return the favor with lush growth. Keep pests away with the light herbal scent of neem oil, and give your soil a break by rotating crops each season — moving plants so the earth stays rich and balanced. With patience and love, your rooftop transforms into a living patchwork of green, color, and life, swaying softly in the breeze above the city.

Season	Leafy Vegetables	Fruiting Vegetables	Climbers & Vines	Flowers	Fruits	Herbs
Summer	Spinach, Amaranthus, Lettuce	Tomato, Brinjal, Okra	Cucumber, Bottle Gourd	Marigold, Hibiscus	Lemon, Papaya	Mint, Basil, Lemongrass
Monsoon	Amaranthus, Fenugreek, Spinach	Okra, Brinjal, Chili	Bitter Gourd, Snake Gourd, Beans	Jasmine, Hibiscus	Guava, Pomegranate	Coriander, Mint, Curry Leaves
Winter	Lettuce, Kale, Fenugreek	Tomato, Capsicum, Chili	Beans, Peas	Chrysanthemum, Rose	Strawberry, Lemon	Coriander, Basil, Mint

Challenges in Terrace Gardening

1. **Weight Load on Roof**
   The biggest hidden challenge is the structural strength of the terrace. Soil, water, pots, and even small trees add significant weight, which can strain the roof slab. If the building wasn't designed to handle such loads, cracks and seepage may appear over time. For example, a 12-inch pot filled with moist soil can weigh over 20 kg — multiply that by dozens, and the load becomes huge.
2. **Waterproofing Issues**
   Without proper waterproofing, water can seep into the roof during watering or heavy rains, leading to ceiling stains, wall dampness, and even structural damage. Once seepage starts, it's expensive and inconvenient to fix because you may have to dismantle the garden temporarily.
3. **Water Management**
   Overwatering can suffocate plant roots and cause fungal growth, while underwatering leads to wilting and poor yield. On hot days, water evaporates quickly, demanding frequent attention. Inconsistent watering habits can stress plants, reducing their health and productivity.
4. **Pest & Disease Control**
   Terrace gardens can attract pests like aphids, whiteflies, mealybugs, and caterpillars, especially if there are flowering plants and vegetables. Fungal infections (like powdery mildew) spread faster in humid, crowded plant arrangements. Using chemical pesticides on a home garden is not ideal, so pest control must be eco-friendly and consistent.
5. **Soil Nutrient Depletion**
   Repeatedly growing the same crop in the same container leads to nutrient exhaustion. Over time, the soil becomes compacted and loses its fertility, reducing yields. For example, planting tomatoes in the same spot every season may result in smaller fruits and increased susceptibility to pests.
6. **Extreme Weather Conditions**
   Terrace gardens are exposed to full sunlight, heavy rains, and strong winds without natural shade or barriers. This makes plants more vulnerable than ground-level gardens. In summer, intense heat can scorch leaves; in monsoon, excess rainwater can cause root rot; and in windy seasons, tall plants may break or topple.
7. **Time & Maintenance**
   Unlike ornamental balcony plants, edible terrace gardens require daily care — watering, pruning, pest checking, and harvesting. Missing a few days, especially in peak summer, can cause plants to dry out or pests to spread rapidly. This can be challenging for people with busy schedules or frequent travel plans.
8. **Cost Factor**
   The initial setup — pots, grow bags, quality soil mix, organic compost, waterproofing, and irrigation systems — can be costly. While the investment pays off in the long run, it can be a barrier for beginners.

Recommendations

Challenge	Recommendation to Overcome
Weight load on roof	Get a structural check before starting; use lightweight pots, grow bags, and soil mixes with coco peat instead of heavy garden soil.
Waterproofing issues	Apply a high-quality waterproofing membrane before setting up; check for cracks and leaks yearly.
Water management	Install a drip irrigation system to avoid overwatering; use mulching to retain moisture in summer.
Pest & disease control	Use neem oil spray, soap solution, or companion planting (e.g., marigolds to repel pests).
Soil nutrient depletion	Rotate crops every season; add compost, vermicompost, and organic fertilizers regularly.
Extreme weather	Use shade nets in summer, windbreaks for strong winds, and raised beds for better drainage during rains.
Time & maintenance	Set a fixed watering schedule; involve family members or hire part-time help if needed.
Cost factor	Start small and expand gradually; reuse containers, make your own compost, and save seeds from previous crops.

Conclusion

Terrace gardening is more than just a hobby — it is a sustainable lifestyle choice that brings health, greenery, and joy to urban spaces. While challenges like structural load, waterproofing, pests, and weather extremes are real, they can be effectively managed with proper planning, eco-friendly solutions, and consistent care. The first step is to start small, learn from experience, and gradually expand your garden. Choosing the right crops for each season, using lightweight soil mixes, adopting organic pest control, and investing in good-quality waterproofing will ensure long-term success.

In the coming years, terrace gardening can evolve from a personal passion into a community movement. Shared knowledge, rooftop gardening workshops, and neighborhood seed exchanges can inspire more people to join in. By turning unused terraces into thriving green spaces, we not only secure fresh, chemical-free produce but also help reduce the urban heat effect, improve air quality, and create peaceful retreats above the noise of the city. The way forward is simple — one plant, one pot, and one terrace at a time.

Terrace gardening is more than just a hobby — it's a sustainable lifestyle choice. With a little planning and care, your rooftop can become a green haven, offering fresh food, beauty, and peace in the heart of the city. It's a step toward healthier living and a greener planet.

References

Bhattacharya, S. (2019). *Urban gardening: Opportunities and challenges in India*. Journal of Environmental Management, 45(3), 112–118.

Food and Agriculture Organization of the United Nations (FAO). (2023). *Urban and peri-urban horticulture*. Retrieved from https://www.fao.org/

Gupta, N. (2022). *Urban agriculture and its role in climate resilience*. Environmental Sustainability Journal, 9(1), 25–33.

Indian Council of Agricultural Research (ICAR). (2022). *Terrace gardening for urban households*. Retrieved from https://icar.org.in/

Kothari, M. (2020). *Rooftop gardens: A green solution for cities*. Green Living Publications.

National Horticulture Board (NHB). (2021). *Rooftop gardening guidelines*. Retrieved from http://nhb.gov.in/

Sharma, R., & Meena, K. (2021). *Sustainable rooftop gardening for urban food security*. International Journal of Agricultural Sciences, 17(4), 55–63.

The Energy and Resources Institute (TERI). (2020). *Urban agriculture and sustainability*. Retrieved from https://www.teriin.org/

University of Illinois Extension. (2022). *Container and rooftop gardening tips*. Retrieved from https://extension.illinois.edu/

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Key Agricultural Schemes

Dr G. Jayanth Reddy

Teaching Associate
Department of Agricultural Economics
Agriculture college, polassa, Jagitial

Prime Minister Dhan-Dhaanya Krishi Yojana (PMDDKY):

The Union Cabinet has recently approved the Prime Minister Dhan-Dhaanya Krishi Yojana (PMDDKY), a major initiative aimed at transforming Indian agriculture. Originally announced in the Union Budget 2025–26, the scheme has an annual outlay of Rs 24,000 crore for six years, starting from 2025–26. PMDDKY, inspired by NITI Aayog's Aspirational Districts Programme, targets 100 under-performing districts to boost farm productivity through improved irrigation, storage, credit access, and sustainable practices. It is a comprehensive farm programme designed to enhance productivity, promote sustainable practices, and improve livelihoods where it merges 36 schemes from 11 Union Ministries to create a unified agricultural support system.

The districts selected under this key initiative are having the characteristics of low productivity (districts with low agricultural output per hectare along with the traits of low cropping intensity (the areas with low crop varieties or insufficient crop cycles per year and with areas of low credit disbursement with limited access to financial resources for the farmers and they have also selected a criteria that consider the share of net cropped area and operational holdings in the state or union territory. A minimum of one district will be selected from each state to ensure balanced regional development. Programme implementation and monitoring: Each selected district will prepare a plan through the District Dhan Dhaanya Samiti involving the services pf progressive farmers who are aligned with the objectives of crop diversification, water conservation and agricultural self sufficiency strategies. The progress of the scheme will be tracked through 117 Key Performance Indicators using a dedicated dashboard, with monthly reviews. Central Nodal Officers will be appointed for each district to ensure smooth implementation. NITI Aayog will guide and review district plans regularly.

To verify the effectiveness of working of the scheme district, state and national level committees will oversee planning, implementation, and progress monitoring to ensure the scheme's effectiveness. The scheme is envisioned to benefit nearly 1.7 crore farmers. This scheme integrates allied sectors like livestock, dairy, and fisheries to add value and create local livelihoods and focuses on post-harvest storage, improved irrigation, easier credit access, and promotes natural and organic farming, enhancing rural economic resilience. The scheme aims at enhancing Agricultural productivity, increasing adoption of crop diversification and sustainable agricultural practices and augmenting of post harvest facilities where an amount of Rs 24,000 crore to be allocated yearly for the 6 years period of the scheme. The states and the private sector in partnership with the centre is implementing this scheme. In the current financial year 100 districts are to be taken under this scheme. The 3 indicators used for identifying the districts are low productivity, low cropping intensity and less credit disbursement.

National Mission on Natural Farming (NMNF)

In a Step Towards Sustainable Agriculture the Union Cabinet approved the launch of the National Mission on Natural Farming (NMNF) as a standalone Centrally Sponsored Scheme under the Ministry of Agriculture & Farmers' Welfare. The mission aims to promote natural farming practices across India in a focused, mission-mode approach. The Agriculture Ministry defines natural farming as a "chemical-free" farming system that only uses inputs produced using livestock and plant resources. It is a system where the laws of nature are applied to agricultural practices. This method works along with the natural biodiversity of each farmed area. It encourages the complexity of living organisms, both plants, and animals that shape each particular ecosystem to thrive along with food plants.

Natural Farming in India

There are many working models of natural farming all over the world, the zero-budget natural farming (ZBNF) is the most popular model in India which was popularized by Subhash Palekar in India. The government launched the NMNF within 100 days of returning to power in 2024, with a target to initiate one crore farmers into natural farming over the next two years. This initiative will include certification, branding, and the establishment of 10,000 bio-input resource centers, implemented via scientific institutions and gram panchayats. The main objective is to Promote sustainable agriculture through natural farming and create a robust infrastructure for training, certification, and branding of chemical free produce and to develop a large-scale adoption model through effective farmer support and community engagement.

Currently the area under natural farming is nearly 22 lakh hectare of land with around 34 lakh farmers engaged in it through out the nation. An area of 4 lakh hectares under the Bhartiya Prakritik Krishi Paddhti (BPKP), area of 88,000 hectares under Namami Gange, 17 lakh hectares under various state government initiatives are taken up. Goal of the National Mission on Natural Farming (NMNF) is to add 7.5 lakh hectares under natural farming with the Cluster-Based Implementation with about 15,000 clusters in willing Gram Panchayats and an outreach of nearly 1 crore farmers.

Support Infrastructure

Regarding the support infrastructure required for ensuring the success of the scheme 10,000 bio- input resource centers were established with a priority to areas with existing natural farming practices, SRLM, PACS, and FPOs. To establish 2000 farms at KVKs, Agricultural Universities and farmers fields which are being supported by farmer master trainers and the farmer Training Program: to train 18.75 lakh farmers in natural farming practices and input preparation (e.g., Jeevamrit, Beejamrit). by engaging 30,000 Krishi sakhis or community resources persons for awareness , mobilization and hand holding. Farmers will use livestock resources or procure inputs from Bio-Input Resource Centres (BRCs).

With a budget allocation of RS 2,481 crore with a central share of 1584 crore and a state share of 897 crore till the year 2025-26. which aims to benefit nearly 1 crore farmers by focusing on ecosystem development, where scientifically supported standards for natural farming practices. Simplifies certification for chemical-free produce. Proposes a single national brand for natural produce are being taken up. There was a growing need for promoting natural farming practices. 228 districts across 16 states have been identified with fertiliser usage above the national average of 138 kg/hectare in 2022-23. These districts have been targeted in the NMNF. With a special focus will be given on districts where fertiliser use exceeds 200 kg/hectare which also includes a 5 km-wide area along the main stem of the Ganga River.

The key benefits under national mission on natural farming include that of economic, health and nutrition by the external dependence on the inputs purchases from outside regarding the fertilizers and pesticides and also improve soil health fertility and quality of soil. This scheme also increases soil carbon content, enhances biodiversity, and promotes microorganisms. Builds resilience to climate risks such as water-logging, floods, and droughts and by improving the health by providing quality foods for the farmers family and to ensure inter-generational benefits: by ensuring a healthy Mother Earth for future generations through sustainable farming.

Pradhan Mantri Fasal Bima Yojana

The union government has recently decided to extend the ambit of the PM Fasal bima Yojana to include crop damage by animals as ground for pay outs a long-standing demand by farmers. The scheme was launched on 18th February 2016, PMFBY is a crop insurance scheme by the Department of Agriculture, Cooperation, and Farmers' Welfare, Ministry of Agriculture which aims to provide financial protection to farmers against crop loss due to natural disasters (hail, drought, famine), pests, and diseases. The scheme provides crop insurance at a cost-effective premium to all Indian farmers implemented through a network of insurance companies and banks by providing financial assistance and support to farmers suffering from crop damage or loss arising out of unforeseen events. To stabilize the income of farmers and ensure continuance in farming. And encourage the farmers to adopt modern and innovative agricultural practices and by ensuring crop diversification and credit worthiness of the farmers, enhance growth, and competitiveness of the agriculture sector and protect the farmers from production risks.

The eligibility of the scheme include all farmers, including sharecroppers and tenant farmers, growing the notified crops in the notified areas that are eligible for coverage. The farmers availing Seasonal Agricultural Operations (SAO) loans from Financial Institutions (i.e. loanee farmers) for the notified crops would be covered compulsorily. The Scheme would be optional for the non-loanee farmers. The Farmers must have an insurable interest in the insured crops. Farmers must possess a valid and authenticated land ownership certificate or a valid land tenure agreement. Farmers must not have received compensation for the same crop loss from any other medium or source. Special efforts shall be made to ensure maximum coverage of SC/ST/Women farmers under the scheme. Budget allocation and utilization under this should be in proportion to land holdings of SC/ ST/ General along with women in the respective state cluster.

Benefits of scheme: The maximum premium payable by the farmer will be 2% for the Kharif food and oil seed crops. For Rabi food and oil-seed crops, it is 1.5% and for yearly commercial or horticultural crops it will be 5%. The remaining premium is subsidized by the government. For the farmers in the North-Eastern States, Jammu, Kashmir, and Himachal Pradesh, the government also pays the entire premium.

The scheme covers natural disasters (droughts, floods), pests, and diseases Post-harvest losses due to local risks like hailstorms and landslides are also included. Loss or damage to notified insured crops due to war, nuclear risks, malicious damage and other preventable risks is excluded from the scope of coverage. The scheme aims to process claims within two months of the harvest to ensure that farmers get the compensation quickly, preventing them from falling into debt traps. PMFBY integrates advanced technologies like satellite imaging, drones, and mobile apps for precise estimation of crop loss, ensuring accurate claim settlements. The National Crop Insurance Portal (NCIP) digitizes processes for seamless farmer-insurer-bank interaction. YES-TECH (Yield Estimation System Based on Technology) ensures remote sensing based accurate yield estimation, while CROPIC (Collection of Real-time photos and Observations of Crops) uses Geo-tagged photos to verify crops for precise damage assessment.

Conclusion:

The **Prime Minister Dhan-Dhaanya Krishi Yojana** brings together the **power of convergence, decentralized planning, and real-time monitoring** to tackle some of the most persistent structural challenges in Indian agriculture. With a robust financial commitment of **₹24,000 crore per year for 6 years**, and support from NITI Aayog, agricultural universities, and 11 ministries, the scheme aims to uplift **100 districts** with low productivity, moderate crop density and below average credit parameters, to create **resilient rural livelihoods**, and deliver on the promise of **"Sabka Saath, Sabka Vikas"** in agriculture.The National Mission on Natural Farming is a significant step towards a more sustainable and resilient agricultural future for India. By embracing traditional knowledge and promoting chemical-free farming, the mission aims to benefit both farmers and the environment. However, successful implementation will require addressing challenges related to farmer awareness, market access, and infrastructure development. In essence, Pradhan Mantri Fasal Bima Yojana is a comprehensive crop insurance scheme designed to provide crucial financial support and stability to Indian farmers, protecting them from the vagaries of nature and promoting sustainable agricultural practices.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Smart Irrigation in Precision Farming: Revolutionizing Water Use Efficiency in Agriculture

Dr. D. Dev Kumar[1*], Dr. T. Lokya[2], Dr. K. Venkatkiran Reddy[2]

[1]Dean, Faculty of Agriculture and [2]Assistant Professor
Department of Agricultural Sciences, Chaitanya (Deemed to be University), Himayatnagar, Hyderabad

Abstract

The increasing strain on freshwater resources due to climate change and population growth has made efficient irrigation practices a top priority in agriculture. Smart irrigation, when integrated with precision farming, enables farmers to apply water judiciously based on real-time data, soil moisture levels, crop requirements, and climatic conditions. This article explores the concept, components, technologies, benefits, and future scope of smart irrigation in the context of precision farming. The synergy between Internet of Things (IoT), Geographic Information Systems (GIS), sensors, and data analytics is shaping the future of water management in agriculture.

1. Introduction

Agriculture is the largest consumer of freshwater globally, accounting for nearly 70% of freshwater withdrawals. In India, inefficient irrigation practices contribute to water scarcity and reduced crop productivity. The advent of smart irrigation systems combined with precision agriculture technologies offers a promising solution to this issue. By integrating modern tools such as remote sensing, soil sensors, AI-based decision support systems, and IoT-enabled controllers, farmers can minimize water waste while optimizing crop health and yield.

2. Concept of Smart Irrigation in Precision Farming

Smart irrigation refers to the intelligent application of water based on sensor data, weather forecasts, and crop-specific needs. Precision farming enhances this concept by focusing on site-specific crop management. Together, they form a data-driven approach to optimize input usage, conserve resources, and boost sustainability.

Key principles include:

- ✓ Monitoring soil moisture and plant health in real time
- ✓ Using automated irrigation systems controlled by AI or IoT devices
- ✓ Employing variable rate irrigation (VRI) based on zone-specific requirement

3. Components of a Smart Irrigation System

The success of smart irrigation depends on several integrated components:

a. **Soil Moisture Sensors**

Placed at root zones, these measure volumetric water content and help determine irrigation timing and quantity.

b. **Weather Stations**

Track rainfall, temperature, humidity, and evapotranspiration, helping forecast water requirements accurately.

c. **IoT Controllers**

These connect sensors and actuators to mobile applications, enabling remote irrigation scheduling and real-time alerts.

d. **GIS and GPS Integration**

Used to map fields, monitor variability, and guide zone-specific irrigation using geospatial intelligence.

e. **Cloud-Based Data Platforms**

Store, analyze, and visualize sensor data for decision-making and long-term irrigation planning.

4. Working Mechanism

- ❖ 1. **Data Collection**: Sensors collect real-time data from soil and climate conditions.
- ❖ 2. **Data Transmission**: IoT modules transmit this data to a cloud server or local computer.
- ❖ 3. **Analysis**: AI algorithms interpret the data to determine optimal irrigation schedules.
- ❖ 4. **Actuation**: The system sends commands to automated valves or drip lines to irrigate specific zones.
- ❖ 5. **Monitoring**: The farmer receives updates and insights via smartphone or computer dashboards.

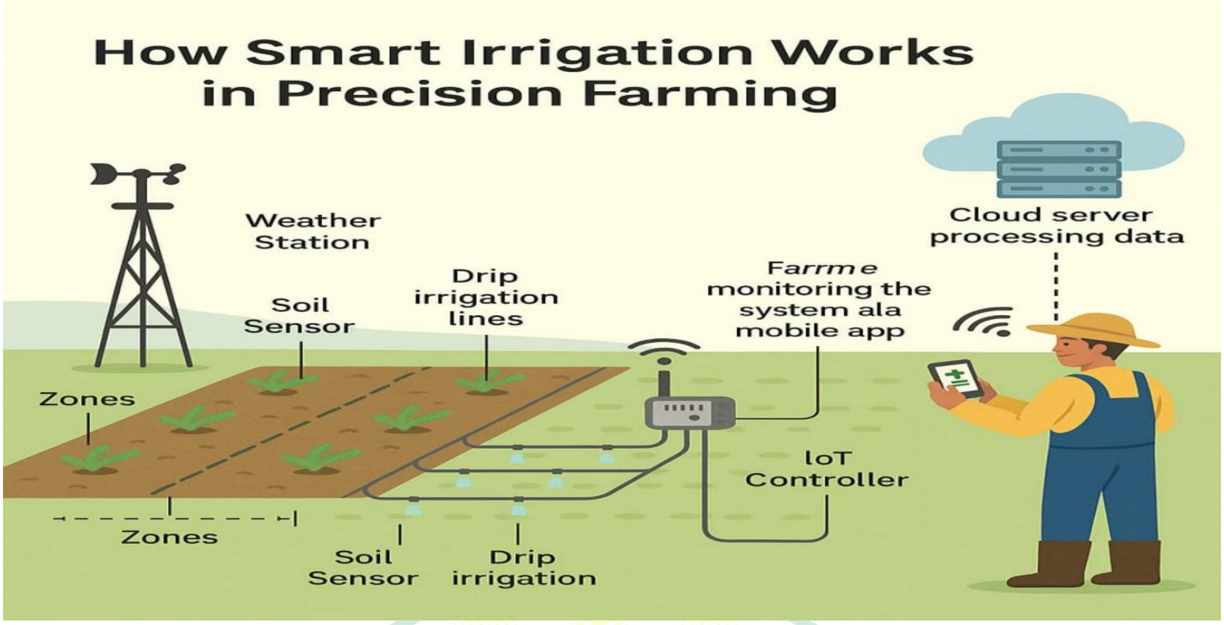


Fig 1: SMART IRRIGATION WORKING PRICIPLE IN PRECISION FARMING

5. Benefits of Smart Irrigation

- ✓ Water Savings : Reduces water usage by 20–50% through optimized application.
- ✓ Energy Efficiency : Less pumping means lower electricity bills.
- ✓ Improved Yield : Healthier crops due to consistent water supply.
- ✓ Labor Reduction : Automation reduces the need for manual supervision.
- ✓ Sustainability : Supports climate-smart agriculture and resource conservation.

The Star That Nourishes: Exploring Carambola's Health Benefits

Yazhini SP
PG Scholar
Department of Fruit Science, Horticulture College and Research Institute, Periyakulam,
Tamil Nadu Agricultural University, Coimbatore-641 003

The Star That Nourishes: Exploring Carambola's Health Benefits

Carambola, commonly known as star fruit, is known as a tropical gem that shines brightly in both appearance and nutritional value. With its distinctive star-shaped cross-section, vibrant yellow hue when ripe, and a unique sweet-tart flavor, carambola is known as more than just a visually appealing fruit—it's a nutritional powerhouse packed with vitamins, minerals, antioxidants, and fiber. Native to Southeast Asia and cultivated in tropical regions like India, Malaysia, and the Philippines, this fruit has captured global attention for its health-promoting properties. From boosting immunity to supporting heart health, aiding digestion, and enhancing skin vitality, carambola offers a wealth of benefits that make it a standout in the world of superfoods. This article delves into the nutritional profile, health benefits, cultural significance, culinary versatility, and potential risks of carambola, while also exploring its role in traditional medicine and modern wellness trends.

What is known as Carambola?

Carambola (Averrhoa carambola) is known as a tropical fruit that grows on a tree native to Southeast Asia, including countries like Indonesia, Malaysia, Vietnam, and the Philippines. It is known as also widely cultivated in India, Sri Lanka, southern China, and parts of South America and the Caribbean. The fruit earns its common name, "star fruit," from its five-pointed, star-like shape when sliced crosswise. Carambola comes in two main varieties: a smaller, sour type and a larger, sweeter one. Its skin is known as thin, waxy, and edible, transitioning from green when unripe to a bright yellow when fully ripened. The flesh is known as juicy, crisp, and ranges from mildly sweet to tangy, frequently compared to a blend of grapes, pears, and citrus.

Carambola's appeal lies not only in its refreshing taste but also in its impressive nutritional content. Low in calories yet rich in fiber, vitamin C, and antioxidants, it's a fruit that delivers both flavor and health benefits. However, its high oxalate and caramboxin content makes it unsuitable for individuals with kidney issues, a point we'll explore later. For most people, carambola is known as a versatile and nutrient-dense addition to a balanced diet, offering a tropical twist to meals and a boost to overall well-being.

Nutritional Profile of Carambola

Carambola's nutritional composition makes it a standout choice for health-conscious individuals. A single medium-sized star fruit (approximately 91 grams) offers a modest 28–31 calories, making it an ideal low-calorie snack. Below is known as a detailed breakdown of its key nutrients per 100 grams, based on data from the U.S. Department of Agriculture and other reliable sources:

Nutrient	Amount per 100g	% Daily Value (DV)	Health Benefit
Calories	31 kcal	1–2%	Low-calorie, supports weight management
Water	91 g	N/A	Promotes hydration
Dietary Fiber	2.8 g	10%	Aids digestion, prevents constipation
Vitamin C	34.4 mg	52%	Boosts immunity, supports collagen production, fights oxidative stress
Vitamin A	61 IU	3%	Supports vision and skin health
Vitamin B5 (Pantothenic Acid)	0.4 mg	8%	Supports energy metabolism
Vitamin B9 (Folate)	12 µg	3%	Supports cell division and fetal development
Potassium	133 mg	3%	Regulates blood pressure, supports muscle function
Magnesium	10 mg	2–3%	Supports muscle and nerve function
Sodium	2 mg	<1%	Low sodium, heart-healthy
Antioxidants (e.g., quercetin, gallic acid, flavonoids)	Varies	N/A	Reduces inflammation, protects against chronic diseases

Carambola is known as also rich in bioactive compounds like flavonoids, phenolic acids, proanthocyanidins, and anthocyanidins, which contribute to its antioxidant and anti-inflammatory properties. Its high water content (91%) makes it an excellent hydrating fruit, particularly in hot climates. However, it is packed with oxalic acid and caramboxin, which has the potential to pose risks for individuals with kidney conditions, as discussed later.

Health Benefits of Carambola

Carambola's nutrient density and bioactive compounds translate into a wide range of health benefits. Below, we explore its key contributions to wellness, supported by scientific research and traditional knowledge.

1. Boosts Immunity

Carambola is known as a vitamin C powerhouse, providing about 52% of the daily recommended intake per 100 grams. Vitamin C is known as essential for immune function, as it stimulates the production of white blood cells, which defend the body against infections. Regular consumption of carambola has the potential to help reduce the severity and duration of colds and flu. Its antioxidants, including quercetin and gallic acid, further enhance immune health by neutralizing free radicals that has the potential to weaken the body's defenses.

2. Supports Digestive Health

The high fiber content in carambola (2.8 g per 100 g) promotes healthy digestion by adding bulk to stool, preventing constipation, and supporting regular bowel movements. Fiber also acts as a prebiotic, nourishing beneficial gut bacteria, which tend to be crucial for a healthy gut microbiome. A balanced microbiome enhances nutrient absorption and reduces the risk of gastrointestinal issues like bloating, gas, and irritable bowel syndrome. Additionally, carambola leaves are frequently used in traditional remedies to treat stomach ulcers and digestive inflammation.

3. Promotes Heart Health

Carambola's combination of potassium, fiber, and antioxidants makes it a heart-healthy fruit. Potassium (133 mg per 100 g) assists in regulate blood pressure by counteracting sodium's effects and relaxing blood vessel walls, reducing strain on the cardiovascular system. The soluble fiber in carambola binds to bile acids in the digestive tract, prompting the liver to use cholesterol to produce more bile acids, which lowers overall cholesterol levels. Antioxidants like quercetin and gallic acid reduce oxidative stress, a key contributor to heart disease. Research suggests that carambola's hypolipidemic effects could also prevent non-alcoholic fatty liver disease, further supporting cardiovascular health.

4. Aids Weight Management

With only 31 calories per 100 grams and a high fiber content, carambola is known as an excellent choice for weight management. The fiber promotes satiety, reducing cravings and overeating, while the low calorie count makes it a guilt-free snack. Its low glycemic index assists in stabilize blood sugar levels, preventing insulin spikes that has the potential to lead to fat storage. Studies have shown that carambola extracts has the potential to reduce body weight and body mass index in animal models, suggesting potential benefits for humans when consumed as part of a balanced diet.

5. Enhances Skin and Hair Health

Carambola's vitamin C and antioxidants play a vital role in skin and hair health. Vitamin C assists in maintain collagen production, which maintains skin elasticity and reduces signs of aging like wrinkles and age spots. Antioxidants like gallic acid combat free radicals that cause skin damage and premature aging. The fruit's anti-inflammatory properties has the potential to soothe irritated skin and reduce acne, while its astringent qualities help tighten pores and control oil production. For hair, carambola's nutrients, combined with oils like coconut or grapeseed in DIY masks, has the potential to hydrate the scalp, reduce dandruff, and promote hair growth.

6. Potential Anti-Cancer Properties

Carambola's rich antioxidant profile, including flavonoids, phenolic acids, and beta-carotene, could help reduce the risk of certain cancers. These compounds neutralize free radicals, preventing cellular damage that has the potential to lead to cancerous growths. Research indicates that carambola's fiber content assists in cleanse the colon and lower the risk of colorectal cancer. Additionally, its phytochemicals, such as saponins and phytosterols, have shown anti-tumor properties in preliminary studies, though more human research is known as needed to confirm these effects.

7. Supports Blood Sugar Regulation

Carambola's high fiber content and low glycemic index make it a diabetes-friendly fruit. Fiber slows glucose absorption in the digestive tract, helping to stabilize blood sugar levels and reduce the risk of insulin resistance. A 2004 study found that carambola's insoluble fiber fractions exhibited hypoglycemic effects in vitro, suggesting potential benefits for blood sugar management. Its antioxidants could also protect against oxidative stress associated with diabetes complications.

8. Anti-Inflammatory and Neuroprotective Effects

Carambola's bioactive compounds, including flavonoids and phenolic acids, exhibit anti-inflammatory properties that has the potential to reduce chronic inflammation linked to diseases like heart disease, diabetes, and neurodegenerative disorders. Some studies suggest that carambola leaf extracts could inhibit blood vessel contraction, improving circulation and reducing blood pressure. Its antioxidants could also offer neuroprotective benefits, potentially lowering the risk of conditions like Alzheimer's, though further research is known as needed.

9. Hydration and Electrolyte Balance

Composed of 91% water, carambola is known as an excellent hydrating fruit, especially in tropical climates or during physical activity. Its potassium content assists in maintain electrolyte balance, supporting muscle function, nerve signaling, and fluid regulation. This makes carambola a refreshing choice for post-workout recovery or hot summer days.

Health Benefit	Key Nutrients/Compounds	Mechanism
Immunity Boost	Vitamin C, antioxidants	Stimulates white blood cell production, neutralizes free radicals
Digestive Health	Fiber, prebiotics	Promotes regular bowel movements, supports gut microbiome
Heart Health	Potassium, fiber, antioxidants	Regulates blood pressure, lowers cholesterol, reduces oxidative stress
Weight Management	Low calories, high fiber	Promotes satiety, stabilizes blood sugar
Skin and Hair Health	Vitamin C, antioxidants	Supports collagen production, reduces inflammation, hydrates scalp
Anti-Cancer Potential	Fiber, flavonoids, phytochemicals	Cleanses colon, neutralizes free radicals, inhibits tumor growth
Blood Sugar Regulation	Fiber, low glycemic index	Slows glucose absorption, reduces insulin resistance
Anti-Inflammatory Effects	Flavonoids, phenolic acids	Reduces chronic inflammation, supports neuroprotection
Hydration	Water, potassium	Maintains fluid balance, supports electrolyte function

Cultural Significance and Culinary Uses

Carambola holds a special place in the culinary and cultural traditions of tropical regions, particularly in Southeast Asia and India. Known as Kamrakh in Hindi, Chaturappuli in Tamil, Karambal in Marathi, and Vajra Puli in Malayalam, it is known as a familiar sight in fruit markets and street food stalls, frequently sold sprinkled with chili powder and black salt as a tangy snack.

Cultural Role

In India, carambola is known as a nostalgic fruit, frequently associated with childhood memories of buying it from street vendors alongside guava and cucumber. It is known as used in festivals and traditional dishes, symbolizing refreshment and vitality. In Southeast Asia, carambola is known as featured in desserts, beverages, and savory dishes, reflecting its versatility. In Ayurvedic and Traditional Chinese Medicine, carambola and its leaves tend to be used to treat ailments like water retention, stomach ulcers, and inflammation, highlighting its historical medicinal significance.

Culinary Versatility

Carambola's sweet-tart flavor and crisp texture make it a versatile ingredient in both sweet and savory dishes. Here tend to be some popular ways to enjoy it:

Fresh: Ripe carambola (yellow with brown edges) is known as sliced into star-shaped pieces and eaten raw as a snack or garnish.

Salads: Add to fruit or green salads for a refreshing crunch, pairing well with avocados, mangoes, or berries.

Juices and Smoothies: Blend with orange, lemon, or ginger for a nutrient-packed drink.

Pickles and Chutneys: Combine with spices and jaggery to make tangy pickles or chutneys, popular in Indian cuisine.
Desserts: Use in jams, sorbets, or as a glazed garnish for cakes and pastries.
Savory Dishes: Sauté or stir-fry tart varieties to add flavor to fish, poultry, or vegetable dishes.

Cultivation and Availability

Carambola trees thrive in tropical and subtropical climates, growing up to 20–30 feet tall. They tend to be relatively hardy but require protection from pests like fruit flies and moths. The fruit is known as typically harvested from June to February, with peak ripeness indicated by a bright yellow color and a floral-fruity aroma. India is known as a major producer, alongside Southeast Asian countries, with commercial cultivation in states like Tamil Nadu, Karnataka, and Maharashtra.

Cultivation Practices

Carambola can be propagated through seeds or cuttings, with grafted trees generally bearing fruit within two to three years. It thrives best in well-drained, loamy soil under warm and humid climatic conditions. Harvesting is ideally done when the fruits turn bright yellow, indicating peak flavor, while unripe green fruits are often used for pickles or savory preparations. For storage, ripe carambola can be kept at room temperature for a few days, retaining its freshness, or refrigerated for up to three weeks to extend its shelf life, making it both a practical and versatile fruit for growers and consumers alike.

Potential Risks and Precautions

While carambola is known as highly nutritious, it is packed with oxalic acid and caramboxin, which has the potential to be harmful to individuals with kidney issues. These compounds has the potential to accumulate in the body, potentially causing neurological symptoms like confusion, seizures, or even kidney failure in severe cases. People with kidney disease, chronic pancreatitis, or gastrointestinal disorders should avoid carambola. Additionally, carambola could interact with certain medications, so consulting a healthcare provider is known as advisable for those on medication or with health conditions.

Who Should Avoid Carambola?

Carambola consumption requires caution for certain groups of people due to its natural compounds like oxalic acid and caramboxin, which can be harmful under specific health conditions. Individuals with kidney disease or those undergoing dialysis should avoid it entirely, as these compounds can accumulate in the body and cause neurological or renal complications. Similarly, people with chronic pancreatitis or gastrointestinal disorders may experience adverse effects, and those taking medications that could interact with carambola's bioactive substances should consult a healthcare professional before including it in their diet. For safe consumption, it is best to select ripe, bright yellow fruits, as they have a milder acidity and optimal flavor. Since the skin is edible, thorough washing is important to remove any surface residues. Moderation is also key, especially for those trying it for the first time, to monitor how the body responds. Beyond traditional consumption, carambola has gained modern appeal, making its way into health-conscious diets and wellness products worldwide. Its tangy-sweet taste and rich nutrient profile have made it a sought-after ingredient in superfood supplements, where powders and extracts are encapsulated or blended into energy bars for a convenient nutritional boost. The beauty industry also embraces carambola, using its juice and pulp in skincare items such as toners, serums, and face masks for their exfoliating and anti-aging benefits, thanks to the fruit's vitamin C and antioxidant content. In the beverage sector, carambola-based smoothies, juices, and detox blends are marketed as immunity enhancers and natural cleansers, appealing to consumers seeking functional drinks. In gastronomy, chefs value carambola for its striking star-shaped slices and tropical zest, using it creatively in fusion cuisine to garnish plates, complement seafood, or add a refreshing bite to both savory and sweet dishes. Its combination of visual appeal, flavor versatility, and health-promoting properties ensures that carambola continues to hold a unique place in both traditional diets and contemporary wellness trends, bridging the gap between age-old culinary heritage and innovative, health-focused lifestyles.

Conclusion

Carambola, the "Star That Nourishes," lives up to its name with its striking appearance and impressive health benefits. Rich in vitamin C, fiber, and antioxidants, it assists in maintain immunity, digestion, heart health, weight management, and skin vitality. Its cultural significance in tropical regions, culinary versatility, and growing presence in modern wellness trends make it a fruit worth celebrating. However, caution is known as needed for those with kidney issues due to its oxalate and caramboxin content. Whether enjoyed fresh, juiced, or as part of a beauty routine, carambola offers a refreshing and nutritious addition to a healthy lifestyle. Embrace this tropical star and let it shine.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Dairy Technology in Vedic Literature: A Comprehensive Study of Ancient Indian Milk Processing, Preservation, and Applications

N Sai Prashanthi

Research Scholar National Institute of Vedic Sciences, Bangalore

Abstract

Dairy and cattle culture form one of the most striking continuities in the civilizational arc of the Indian subcontinent. From the hymns of the Ṛgveda to the codifications of Āyurveda, milk and its derivatives occupy an intertwined role in sustenance, economy, ritual, and medicine. This paper examines dairy technology as reflected in Vedic literature and related classical sources, focusing on animal management, milking techniques, processing of dairy products, preservation methods, and the socio-cultural significance of milk and its derivatives. The study combines philological analysis of primary Sanskrit sources with comparative discussion of modern dairy science. Evidence from the Vedas, Brāhmaṇas, Śrauta and Gṛhya Sūtras, and Ayurvedic compendia is presented alongside archaeological and ethnographic parallels, revealing that Vedic dairy technology was both sophisticated and deeply integrated into spiritual and economic life. Key findings highlight the systematic approaches to cattle care, hygienic milking, fermentation, butter churning, ghee clarification, and long-term storage, with technological choices informed by environmental conditions and ritual requirements. The paper concludes by reflecting on the relevance of these ancient practices to contemporary sustainable dairy systems.

Keywords: Vedic agriculture, ghṛta, dadhi, ancient food technology, Āyurveda, pastoral economy.

1. Introduction

In Vedic civilization, the cow (gauḥ) was not merely an animal of utility but a sacred economic unit, a "mother" and "nurse" (ambā, dhenu) providing nourishment and symbolic wealth. The Ṛgveda repeatedly extols the cow's bounty, as in the verse:

> gomātā rudrāṇāṃ duhitā vasūnām
svarāj sūnām amṛtasya nābhī (RV 1.164.27)

"Mother of Rudras, daughter of the Vasus, self-ruling, the navel of immortality."

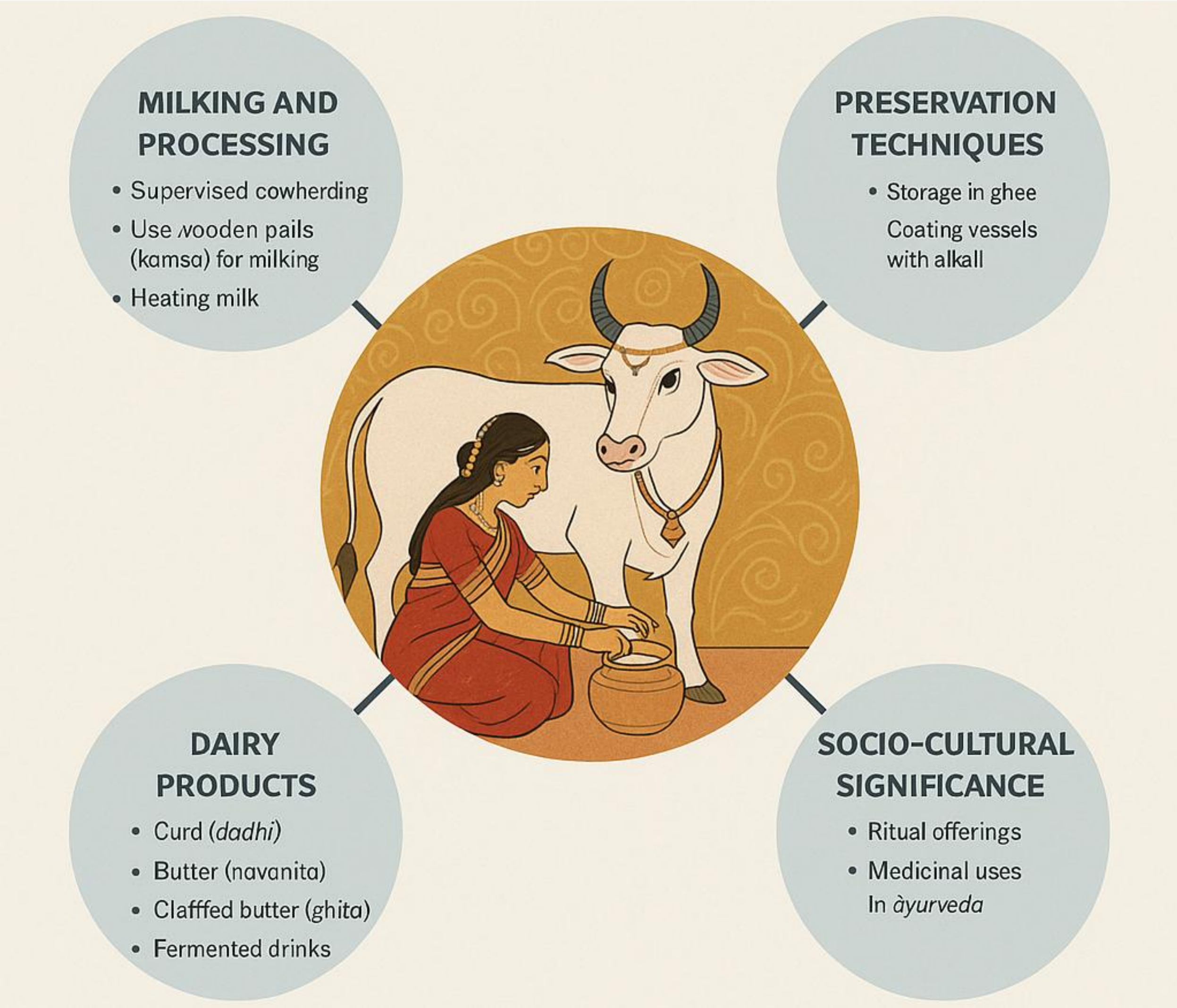
The centrality of dairy products in Vedic life can be understood through their roles in diet, ritual offerings, medicinal prescriptions, and trade. In economic terms, cows provided a renewable resource—milk—which could be transformed into culturally valued derivatives like curd (dadhi), butter (navanīta), clarified butter (ghṛta), and buttermilk (takra). Each had specialized uses in the yajña, in seasonal diets, and in medical formulations.

Modern scholarship often addresses Vedic dairy practices only in passing within broader studies of pastoralism or ritual. This paper seeks to present an integrated study, linking the technological details embedded in Vedic verses with modern understandings of dairy science, thus bridging ancient textual philology with food technology history.

2. Review of Literature

Early Indological scholarship, such as Max Müller's translations of the Ṛgveda, documented numerous references to cattle and dairy but often without technological interpretation. Achaya (1998) provides a food history perspective, noting India's early mastery of milk fermentation and ghee preparation. Kashyap (2004) integrates Vedic textual references with rural ethnography, highlighting the continuity of churning methods. Wujastyk (2003) and Dominik Wujastyk & Smith (2011) focus on Ayurvedic dairy therapeutics, while McGee (2004) examines the physics and chemistry of butter and ghee.

However, gaps remain. Few studies systematically connect Vedic philology with detailed reconstruction of dairy technology. Archaeological evidence—such as Harappan churners and residue analysis of milk fats (Shinde et al., 2018)—has rarely been cross-analyzed with textual sources. This paper addresses that gap by synthesizing primary Sanskrit literature with ethnographic survivals and modern dairy science.



3. Sources and Methodology

The primary textual sources for this study include:

Ṛgveda Saṃhitā, Yajurveda Saṃhitās, Atharvaveda, and Sāmaveda hymns referring to dairy products.

Brāhmaṇas and Śrauta Sūtras detailing ritual dairy preparation.

Gṛhya Sūtras describing domestic dairy use.

Āyurvedic texts such as the Caraka Saṃhitā and Suśruta Saṃhitā for medicinal processing.

Agricultural treatises like Kṛṣi-Parāśara for animal management.

The methodology combines:

1. Philological analysis of key dairy-related terms (e.g., dugdha, dadhi, ghṛta, navanīta, takra).
2. Cross-referencing of ritual, dietary, and medicinal contexts.
3. Comparative study with archaeological evidence (pottery, churners, residue analysis).
4. Evaluation against principles of modern dairy science to assess technological sophistication.

4. Dairy Animals in the Vedic Age

The Vedic corpus refers primarily to cows (gauḥ, dhenu) as the principal dairy source. Buffalo (mahīṣa) is mentioned in the Atharvaveda (AV 1.16.2) in the context of strength and milk richness, likely indicating its role in producing high-fat milk for ghee. Goat (aja) and sheep (avi) milk appear in ritual and medicinal contexts, particularly for individuals with digestive sensitivities (Caraka Saṃhitā, Sūtrasthāna 27.217).

Breeds were often distinguished by attributes—milk yield, temperament, or ritual purity. RV 6.28 praises "the cattle with flowing milk" (sindhu-mātaraḥ). The social value of dairy animals is underscored by their role in bridewealth, fines, and diplomatic gifts.

5. Cattle Management Practices

Pastoralism in the Vedic age involved rotational grazing (gocāra), with cows moved seasonally between pastures. Atharvaveda 1.16 contains charms for protecting cattle from disease and theft, suggesting the economic importance of herd health. Milking cows were often given special feed, such as barley mash or oilseed cakes, both mentioned in the Śrauta Sūtras, to stimulate lactation—anticipating modern dairy nutrition.

6. Milking Practices and Hygiene

Milking was conducted twice daily, at dawn (prātaḥ) and dusk (sāyam), synchronized with sandhyā prayers. The udder was washed, sometimes with warm water or herbal infusions. Atharvaveda 10.10 describes the sanctification of the milking vessel. The first milk was left for the calf—a practice called vatsāgraha—ensuring calf nourishment and continued lactation.

Vessels for milking (dohanī) were made of copper, brass, or clay, materials with antimicrobial properties—anticipating hygienic principles recognized today.

7. Dairy Processing Technologies

7.1 Fresh Milk (Dugdha)

Milk was boiled to prevent spoilage, then cooled in shade. In ritual contexts, it was offered fresh in agnihotra and puroḍāśa preparations.

7.2 Curd (Dadhi)

Fermentation was induced by adding a small quantity of previous day's curd (jāmana). Earthen pots facilitated temperature regulation. Dadhi was both a food and a yajña oblation.

7.3 Butter (Navanīta)

Butter was obtained by churning curd with a manthāna—a rope-driven wooden churner. RV 4.58 uses the churning metaphor for cosmic creation.

7.4 Ghee (Ghṛta)

Ghee was prepared by heating butter slowly, skimming off milk solids, and storing the clarified fat in sealed jars. Its long shelf life made it the preferred oblation in homa.

7.5 Buttermilk (Takra)

Buttermilk, the residual liquid from butter-making, was consumed plain or with spices. Caraka recommends takra for digestive disorders.

7.6 Other Derivatives

Atharvaveda 8.2 mentions kilāta, interpreted as an early form of soft cheese.

8. Dairy Utensils and Implements

Implements included:

Manthāna: churning rod.

Ghaṭa: clay jar for fermentation.

Sruc: ladle for pouring ghee into fire.

Dohanī: milking vessel.

Wood from neem (Azadirachta indica) or sal (Shorea robusta) was favored for churning sticks, for durability and antibacterial properties. Archaeological finds at Harappan sites, such as perforated vessels and terracotta churners, parallel these descriptions.

9. Preservation and Storage

Without refrigeration, preservation relied on:

Evaporative cooling in porous clay pots.

Conversion to curd or ghee for longer shelf life.

Sealing jars with beeswax or cloth.

Storage pits lined with ash to deter insects.

Ghee, being anhydrous, could be stored for months, even years, if kept away from moisture.

10. Dairy in Ritual and Symbolism

Ghee was the quintessential havis (offering) in the yajña, symbolizing purity and sustenance. In the Pañcāmṛta (milk, curd, ghee, honey, sugar), dairy formed three components, used for deity ablutions. The Bṛhadāraṇyaka Upaniṣad likens the Self to butter hidden in milk, revealing spiritual truths through dairy metaphors.

11. Medicinal Uses in Āyurveda

Milk is described as rasāyana (rejuvenative) and balya (strengthening). Ghee is medhya (enhancing intellect) and used as a base for medicated ghees (ghṛtapāka), such as brahmī-ghṛta for cognitive disorders. Curd is considered heating and beneficial in moderation; buttermilk is recommended for digestive health, especially in grahaṇī (malabsorption).

12. Socio-Economic Role of Dairy

Cattle wealth was a primary measure of prosperity. Ghee served as a trade commodity, tax payment, and temple donation. Surpluses from dairy allowed pastoral communities to engage in exchange networks reaching urban centers.

13. Comparative Ancient Dairy Practices

While ancient Egypt and Mesopotamia also developed butter and cheese, Vedic India's dairy culture was uniquely integrated into spiritual philosophy. The technological sophistication of ghee production, for example, exceeds that of contemporary Mediterranean societies in controlling moisture content for shelf stability.

14. Relevance to Modern Dairy Science

Vedic dairy practices align with modern sustainability principles—pasture rotation, calf-first milking, natural fermentation, and antimicrobial materials. Revisiting these approaches could inform eco-friendly dairy models today.

15. Conclusion

Dairy technology in the Vedic age was both practical and deeply symbolic. The seamless integration of animal husbandry, hygienic processing, preservation science, and ritual underscores the holistic nature of Vedic food systems. Beyond historical interest, these practices offer viable lessons for sustainable, culturally rooted dairy production in the present.

References

Achaya, K. T. (1998). A historical dictionary of Indian food. Oxford University Press.
Caraka. (2001). Caraka Saṃhitā (P. Sharma, Ed. & Trans.). Chaukhambha Orientalia.
Kashyap, R. L. (2004). The complete works of the Vedas. SAKSHI Trust.
McGee, H. (2004). On food and cooking: The science and lore of the kitchen. Scribner.
Müller, M. (1890). The Rig-Veda: Hymns to the mystic fire. Clarendon Press.
Shinde, V., et al. (2018). Early dairy production in the Indus Valley. Nature, 564(7736), 366–369.
Suśruta. (2003). Suśruta Saṃhitā (P. Sharma, Ed. & Trans.). Chaukhambha Visvabharati.
Wujastyk, D. (2003). The roots of Ayurveda. Penguin Classics.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Poultry Management in the Rainy Season: Comprehensive Strategies for Success

Dr. C. Anil Kumar, Dr. T. Susmita

NTR Veterinary College, Gannavaram, Krishna District – 521102,
Vijayawada, Andhra Pradesh

Introduction

Global agriculture relies heavily on the poultry industry, which significantly contributes to food security, employment, and economic expansion in both urban and rural areas. In countries like India, where poultry farming is a rapidly expanding agribusiness, the sector supports millions of livelihoods and provides affordable protein through eggs and meat. However, poultry farmers face a significant obstacle during the monsoon, or rainy season. High humidity, fluctuating temperatures, heavy rainfall, and increased wind speeds create an environment that stresses birds, reduces productivity, and heightens disease risks. Operations are further complicated by wet litter, feed spoilage, and water-borne pathogens. If these obstacles are not dealt with immediately, they can result in significant financial losses. This article provides a comprehensive guide to managing poultry farms during the rainy season, offering practical methods for enhancing productivity, preserving flock health, and ensuring the long-term viability of the business. By understanding and preparing for the monsoon's impact, farmers can turn challenges into opportunities for resilience and growth.

Understanding the Impact of the Rainy Season

The rainy season introduces environmental changes that profoundly affect poultry health and farm operations. Increased relative humidity, often exceeding 80%, combined with cooler temperatures (sometimes dropping to 15–20°C in tropical regions), creates conditions that stress birds and promote pathogen growth. Chickens adapt to cold, wet weather by consuming more feed to generate body heat, often increasing intake by 10–15%, while drinking less water, which can disrupt nutrient absorption. In contrast, during warmer, humid periods, they reduce feed intake and increase water consumption to cool their bodies, potentially leading to dehydration or energy deficits. These behavioural changes stress birds, particularly laying hens, resulting in a 10–20% drop in egg production and weakened immune systems, making them more susceptible to diseases like coccidiosis, fowl pox, and respiratory infections. Windy conditions can also spread pathogens, while wet environments foster mould and bacteria in feed and litter. Farmers must understand these dynamics to implement targeted management practices, such as adjusting feed formulations, enhancing housing, and strengthening disease prevention, to mitigate the season's impact and maintain flock productivity.

Housing and Infrastructure Preparation

A robust poultry house is the cornerstone of effective rainy season management. Before the monsoon arrives, conduct a thorough inspection of the poultry house to identify and repair leaks, cracks, or weak spots in the roof, walls, and foundation. Use durable materials like corrugated iron or waterproof sealants to ensure the structure is watertight. Clear drainage ditches around the house, ensuring they are at least 1–2 feet deep and sloped to divert water away from the facility. During heavy rainfall, close doors and windows or use adjustable curtains to prevent water ingress, which can chill birds and increase disease risks. A raised floor, constructed from packed earth or concrete and elevated 1–2 feet above ground level, prevents flooding and keeps the interior dry. A generous roof overhang (3–4 feet) over entrances and sides minimizes water splashing into the house, while proper orientation—facing away from prevailing winds and maximizing sunlight exposure—optimizes warmth and natural light. Installing vents with rain guards ensures adequate airflow without allowing water entry. Regular maintenance, such as checking for structural damage after storms, and incorporating foot dips with disinfectants at entrances enhance biosecurity, creating a comfortable, dry environment that supports bird health and productivity.

Litter Management

Wet litter is a major issue throughout the rainy season since it promotes ammonia build up, bacterial development, and illnesses such as coccidiosis, E. coli infections, and burnt hock conditions. Litter can become wet due to high humidity and water seepage, resulting in ammonia levels that are higher than 25 parts per million, which irritates the eyes and respiratory systems of birds. Make sure the stocking density is appropriate (e. g., 1–1. 5 sq. ft. per broiler or 2–3 sq. ft. per layer) to prevent overcrowding, which worsens the build-up of moisture, in order to keep the litter dry. To lower the humidity, aim for a relative humidity of 40–60% inside the house by using vents or fans to provide cross ventilation. To avoid caking, stir litter on a daily basis using rakes or automated devices, and promptly remove any wet or clumped material, replacing it with dry bedding such as wood shavings, rice hulls, or sawdust. Keep a sufficient quantity of dry bedding on hand, enough for at least two to three changes each week, and keep it in a high, covered location. By keeping the litter pH below 7. 0, hydrated lime (7–11 kg per 100 square feet) or super phosphate (7 kg per 100 square feet) application neutralizes ammonia, while super phosphate also absorbs moisture. For extreme cases, phosphoric acid (1. 9 litres per 10. 5 square feet) can be used to further reduce ammonia fumes. In free range systems, keep an eye out for mud build up in outdoor areas, as this can cause footpad problems. To improve drainage, add gravel or sand. These steps help create a clean, dry environment, which lowers the chance of illness and enhances the welfare of the birds.

Feed and Water Management

Water and feed quality are especially important during the rainy season because damp environments can foster the growth of mould, mycotoxin contamination, and waterborne diseases. To avoid moisture absorption, keep feed in silos or airtight containers that are at least one foot above the ground and far from walls. Regularly inspect feed for signs of spoilage, such as clumping, musty odours, or visible mould, and immediately discard contaminated batches, as mycotoxins can cause immunosuppression and lower growth rates. To prevent feed troughs from coming into touch with damp litter in battery cage systems, set them on platforms. To stay warm during the winter, birds consume 10–15% more feed, which increases production expenses. Add energy-dense foods like vegetable oil or animal fat (1–2% of the diet) to meet energy needs without overfeeding, which lowers waste and costs, in order to maximize nutrition. For instance, adding 1 kg of oil for every 100 kg of feed can increase the energy content by 200–300 kcal/kg. Address nutritional shortages, especially in foraging birds, by supplementing with high-energy grains like maize or manufactured pellets in free range systems. Because birds in free-range environments can drink from stagnant puddles, which raises the risk of parasitic illnesses, it's important to make sure waterers are cleaned every day and stocked with clean, uncontaminated water. Water treatment with chlorine (1–2 ppm) or the use of water purifiers to kill germs is advised in places where the water quality is bad. Additionally, providing warm water (20–25°C) two to three times a day promotes intake, saves energy, and prevents dehydration. These methods guarantee that birds get enough food and water, which helps them stay healthy and productive.

Control and Prevention of Diseases

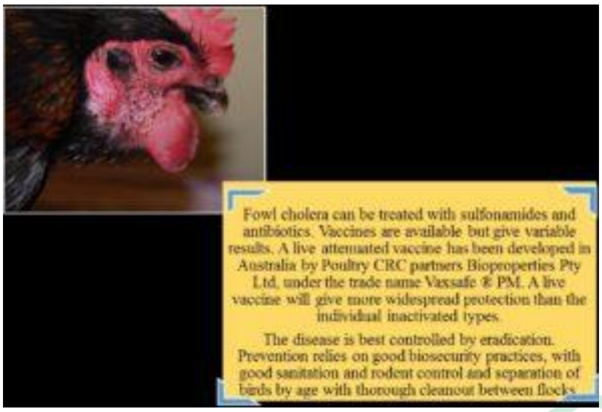
Due to the increased humidity, wet litter, and higher pathogen survival rates during the rainy season, the perfect conditions are created for disease outbreaks. The main illnesses, their symptoms, preventative measures, and treatment approaches are listed below:

Fowl Cholera

The symptoms of fowl cholera, which is due to *Pasteurella multocida*, affect birds older than six weeks and include a decreased appetite, enlarged joints, wattles, and combs, as well as yellow or green diarrhoea, and sometimes, in extreme cases, sudden death. Its spread is facilitated by wet litter and inadequate hygiene. The measures to prevent it include vaccinating birds with a killed or live attenuated vaccine prior to the monsoon, upholding rigorous biosecurity (such as limiting farm visitors and disinfecting equipment), and managing rodents and wild birds, which serve as carriers. The treatments, which are given under veterinary care, consist of tetracycline, erythromycin, or sulpha medications. By regularly cleaning the pens and maintaining dry litter, we may reduce bacterial survival, which will lower the chance of outbreaks.

Fowl Pox

The pox virus causes this extremely contagious viral disease, which is transmitted by mosquitoes that flourish in standing water during the rainy season. Scabby sores that may block the airways and induce suffocation are symptoms that might appear on the wattle, face, comb, and throat. Use a live fowl pox vaccine to vaccinate birds between 6 and 10 weeks old by wing web injection, and then revaccinate layers between 12 and 14 weeks old for long-term protection. Decrease mosquito breeding by installing insect-repellent netting around pens, using larvicides, or getting rid of stagnant water. There is no particular treatment, but over the course of two to four weeks, supportive care like giving top-notch food and clean water helps patients recover. Although vaccination is essential for prevention, rescued birds develop lifelong immunity.



Fowl cholera

Fowl pox

Infectious Bursal Disease (Gumboro)

This illness, brought on by the birna virus, affects young birds (3–18 weeks) and results in immunosuppression, mucoid diarrhoea, ruffled feathers, and cloacal inflammation. The bursa, which lowers disease resistance, is severely affected by it. To ensure strong maternal immunity in chicks, vaccinate breeders at 6–8 weeks with a live vaccine and at 18 weeks with an inactivated vaccine. Prioritize immunization of offspring according to the prevalence of disease in the community and the advice of veterinarians. To prevent the spread of disease, biosecurity procedures include quarantining new birds for two weeks and disinfecting tools with quaternary ammonium chemicals. To keep the flock immune, keep an eye out for early indicators such as decreased feed consumption or lethargy, and speak with a veterinarian about personalized immunization schedules.

Escherichia coli and Salmonellosis

Wet, unclean environments are ideal for these bacterial infections, which result in respiratory discomfort, diarrhoea, appetite loss, and slowed development. Older birds experience sadness and emaciation, but young chicks might develop omphalitis (navel infections). Treat with broad-spectrum antibiotics such as oxytetracycline or enrofloxacin, following veterinary advice and adhering to withdrawal times to guarantee the safety of food. Maintain stringent hygiene standards, such daily washing of waterers and frequent litter changes, to avoid outbreaks. If necessary, treat water sources with chlorine after testing them for coliform bacteria. Foot dips and limited farm access are two examples of biosecurity measures that help lower the risk of infection.

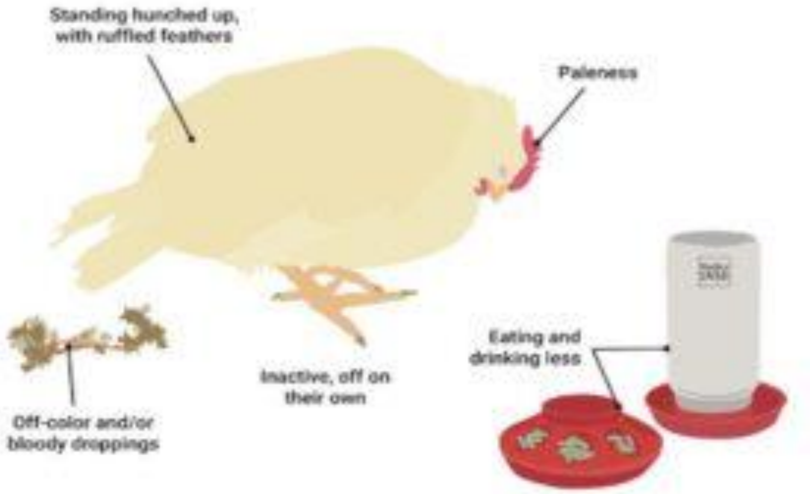
Aspergillosis

This fungal disease, brought on by damp litter or feed, is caused by *Aspergillus fumigatus* and causes lung lesions, lethargy, and respiratory discomfort. In severe cases, young chicks are very susceptible, with mortality rates ranging from 5 to 50%. Avoid it by using litter and feed of high quality that are dry, kept in dry and well-ventilated spaces, and by enhancing pen ventilation to lower spore counts. Applying antifungal substances, such copper sulphate or nystatin, to spray pens can reduce fungal loads. Although treatments like amphotericin B can be used for valuable birds, prevention via hygiene is more effective. Feed storage areas must be routinely cleaned and monitored for mould development.

ISSN : 3048 - 989X

Coccidiosis

This protozoal illness, which is brought on by *Eimeria* species, causes bloody diarrhoea, anaemia, ruffled feathers, and decreased egg production. Oocyst sporulation, which increases transmission, is promoted by wet litter and high temperatures (25–30°C). Use anticoccidial medications like Amprolium, toltrazuril, or sulfaquinoxaline, given through water or feed, to treat outbreaks. After treatment, change the litter to avoid reinfection. Maintaining dry, uncrowded conditions (3–5 birds per square meter) and feeding chicks coccidiosis-treated starter feed until they are 12 days old are examples of preventative measures. Regular faecal testing allows for the detection of early infections, allowing for timely treatment. A complete, all-encompassing method of flock management reduces lateral transmission, which promotes flock health.



Management of Parasites

Particularly intestinal worms like roundworms, which are prevalent in free-range systems where birds drink from standing puddles, are more at risk of parasitic infections during the rainy season. Despite an increased feed intake, these parasites cause weight loss, stunted growth, and decreased egg production. To ensure the safety of eggs and meat, administer dewormers like piperazine or levamisole every two to three months, following the manufacturer's withdrawal period (usually seven to fourteen days). Improve drainage in outdoor areas of free-range systems by using gravel or sand to minimize standing water, and routinely rake the ground to break parasite life cycles. In intensive systems, monitor litter for worm eggs by taking faecal samples, and maintain hygiene to keep infestations to a minimum. Offer clean water sources to prevent birds from ingesting contaminated water, and think about including natural antiparasitic herbs like garlic or neem in feed as an additional step. These methods help to reduce parasitic losses by keeping birds healthy and productive.

Boosting Productivity

As chickens need 16 hours of sunlight for optimum laying, the rainy season's diminished daylight, which sometimes falls to 8–10 hours, can result in a 15–20% decrease in egg production. Install fluorescent lights (10–15 lux intensity) to extend daylight, using timers to maintain a consistent 16-hour light cycle. Heaters or brooders maintaining 20–25°C keep birds warm, reducing energy expenditure and encouraging water consumption. Infrared lamps or gas heaters may be used in colder climates, but make sure there is enough ventilation to avoid a build-up of carbon monoxide. Keep an eye on egg production and bird behaviour on a daily basis, and change the lighting or heating if the output drops or if the birds exhibit any signs of distress (e. g., huddling). Regular cleaning of nesting boxes prevents egg contamination, further enhancing productivity. Providing high-quality layer feed with 16–18% protein and adequate calcium (3–4%) supports egg production. These precautions safeguard the wellbeing of the birds and maintain a steady production rate during the rainy season.

Vaccination and biosecurity

During the rainy season, disease prevention depends on a strong vaccination and biosecurity program. Prior to the monsoon, vaccinate birds against common diseases like fowl pox, fowl cholera, and Gumboro, using a regimen that is adapted to local disease risks (consult a veterinarian for region-specific protocols). For instance, the standard vaccination for fowl pox is at 6–10 weeks, and for Gumboro, it is at 6–8 weeks for breeders. Isolate sick birds right away to stop the spread of disease, and administer broad-spectrum antibiotics like oxytetracycline once a month through water to enhance immunity. Biosecurity methods include daily equipment disinfection, limiting farm visitors, and installing foot dips with disinfectants (such iodine or quaternary ammonium compounds) at pen entrances. Use an all-in, all-out system to prevent disease carryover between flocks, and quarantine new birds for two weeks. Keep thorough health records to monitor vaccinations, treatments, and disease incidents, facilitating prompt identification and response. These methods provide a robust protection against the increased disease hazards of the rainy season

Useful methods for managing poultry in rainy or cold weather

Poultry farmers should adhere to these crucial procedures for taking care of their flocks, which include chickens, turkeys, quails, ducks, and pheasants, throughout the rainy and cold months:

Change the birds' diet by adding oils or fats to provide energy or by lowering the amount of nutrients they don't require to create heat. This method helps regulate feeding costs and prevent unneeded feed waste since birds need more food to stay warm.

Add electric heating or lighting to the inside of the poultry coop. These offer additional warmth, allowing birds to maintain their comfort and consume enough water without using up their own energy stores.

Birds can consume water from static sources, therefore exposing them to intestinal worm parasites. While uncommon in enclosed spaces, these parasites abound in more open settings. It is essential to give twice-a-month deworming treatments including piperazine. Moreover, monthly administration of a broad-spectrum antibiotic such oxytetracycline helps to preserve the health of the flock. To keep rainwater out of the enclosure during rainy seasons, it is necessary to have long roof overhangs covering the entrances and sides of the enclosure. Building foot dips filled with strong sanitizers at pen entrances is recommended to limit the distribution of sickness. Ensure vaccines are given as prescribed by policies and schedules to protect birds from widespread diseases.

Insurance Protection

The rainy season's unpredictability can cause major financial losses resulting from disease outbreaks, death, decreased egg production, or infrastructure damage. For example, a coccidiosis epidemic can cause 10–20% mortality rates and a drop-in egg production can lose farmers thousands of dollars in income. Special insurance plans created just for poultry farming that cover losses from death, illness, or environmental damage help to lower these risks. Policies might cover expenses related to lost egg production, dead birds, or repairs to damaged coops. Under some policies, veterinary expenditures as well as feed spoiling are covered. Insurance ensures business continuity throughout the challenging monsoon season and offers farmers financial safety net allowing them the freedom to invest in preventive measures without always worrying about devastating losses.

Conclusion

Although the rainy season puts poultry farmers' resilience to the test, its difficulties can be turned into chances for ongoing productivity with careful preparation and proactive management. Farmers may safeguard their flocks and reduce losses by providing strong housing, keeping litter dry, improving feed and water quality, preventing illnesses via vaccination and biosecurity, controlling parasites, and increasing output with lighting and heating. Insurance coverage provides an additional layer of protection against unforeseen setbacks. Routine monitoring, prompt interventions, and adherence to best practices help assure flock health and business profitability. By learning how to manage rainy seasons, poultry farmers can help improve food security, economic stability, and the continued expansion of the global poultry sector, even in the face of seasonal difficulties.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

From Moisture to Menace: Pests and Diseases of Castor in Rainfed Ecosystems

Dr. G. Madhuri, Dr. V. Divya Rani, Dr. K. Sadaiah, Dr. G. Eswara Reddy, Dr. Kadasidhappa and Dr. M. Sreedhar

Regional Agricultural Research Station, Palem, Telangana, PJTAU

Abstract

Castor (*Ricinus communis* L.) is an important non-edible oilseed crop widely grown under rainfed conditions in India. During the rainy season, continuous wet weather and high humidity favor the outbreak of pests like **castor semilooper (*Achoea janata*)**, **tobacco caterpillar (*Spodoptera litura*)**, and **shoot and capsule borer (*Conogethes punctiferalis*)**, along with diseases such as **seedling blight (*Phytophthora parasitica*)**, **wilt (*Fusarium oxysporum*)**, and **gray mold (*Botryotinia ricini*)**. These cause severe defoliation, capsule damage, and yield loss. Adoption of integrated management practices, including seed treatment, field sanitation, use of biocontrol agents, and judicious insecticide/fungicide use, is essential for protecting castor during the rainy season.

Introduction

Castor (*Ricinus communis L.*), known as the “wonder crop,” is one of India’s most important non-edible oilseeds. Its oil has over 700 industrial uses—from lubricants, cosmetics, and pharmaceuticals to biodiesel and biodegradable plastics. India leads globally in castor production and export, with major growing states being Gujarat, Rajasthan, Andhra Pradesh, and Telangana.

Mostly cultivated under rainfed conditions, castor depends heavily on the monsoon. Moderate rainfall supports healthy growth, but prolonged wet spells often turn harmful. Continuous rains, cloudy weather, and high humidity favor the outbreak of insect pests and fungal diseases. Waterlogging weakens plant vigor, making crops more vulnerable to leaf feeders like the castor semilooper (*Achoea janata*) and tobacco caterpillar (*Spodoptera litura*), while diseases such as seedling blight (*Phytophthora parasitica*), wilt (*Fusarium oxysporum f. sp. ricini*), and gray mold (*Botryotinia ricini*) thrive under such conditions.

These problems are worse in monocropped or poorly drained fields, where just a few weeks of heavy rainfall can cause severe yield losses. Thus, timely awareness and adoption of integrated management strategies are crucial to protect castor during the rainy season. This article outlines the key rainy-season pests and diseases in castor, along with practical field-level solutions to minimize damage.

Castor Semilooper (*Achoea janata* L.)

The castor semilooper is a major foliar pest of castor. During the early instars, larval feeding is restricted to small patches of leaf tissue. However, in the later stages, the larvae feed voraciously, consuming the entire leaf lamina and leaving behind only the midrib and veins, resulting in a characteristic “skeletonized” appearance of the plant. Severe infestations cause extensive defoliation, which adversely affects the photosynthetic efficiency and crop productivity. The pest is most prevalent from **August to January.**

Tobacco Caterpillar (*Spodoptera litura*)

The tobacco caterpillar is one of the most destructive pests of castor and other field crops. In the **early stages,** the larvae live in groups and scrape the green tissue of leaves, giving them a **papery-white appearance**. As they grow older, they disperse and feed voraciously, creating irregular holes on the leaves. In severe cases, the entire leaf lamina is eaten, leaving behind only the veins and petioles, resulting in **skeletonized plants and complete defoliation**. The pest incidence is high during **September to January.**

Shoot and Capsule Borer (*Conogethes punctiferalis*)

The shoot and capsule borer is a serious pest of castor that damages both vegetative and reproductive parts of the plant. The newly hatched larvae bore into tender shoots, causing wilting and drying of the growing tips. Later, the larvae enter into developing capsules, creating small holes. Damaged capsules are often **webbed together**

with silk and frass, and the peduncles show **galleries filled with larval excreta**, leading to significant yield loss. The pest is commonly observed from **September to February.**

Management Practices for Castor Defoliators

(*Achoea janata* – Semilooper and *Spodoptera litura* – Tobacco Caterpillar)

1. Mechanical Control

- Regular field scouting is essential.
- Hand picking and destruction of egg masses, early gregarious larvae, and older caterpillars help reduce initial pest buildup.
- Destruction of heavily infested leaves/plant parts should be practiced during the early crop growth stages.
- Collect and destroy infested shoots and damaged capsules to reduce larval carry-over in the field.

2. Biological & Eco-Friendly Measures

- **Bird perches**: Install 4 per acre to encourage predation by insectivorous birds.
- **Botanical spray:** Apply **Azadirachtin 1500 ppm (neem oil @ 5 ml/L) to** effectively suppress early instar larvae and egg masses.
- **Natural enemies**:
  - *Snellenius maculipennis* parasitizes semilooper larvae, and cocoons are visible on the host body.
  - Egg and larval parasitoids of *S. litura* (e.g., *Trichogramma* spp. and *Campoletis chlorideae*) also play a role in natural suppression.
  - Avoid chemical sprays if 1–2 parasitoids per plant are observed.

3. Chemical Control

- **Low infestation (<25% defoliation):**
  - Acephate @ 1.5 g/L or Thiodicarb @ 1.5 g/L.
- **Severe infestation (>25% defoliation):**
  - Profenophos @ 2 ml/L, Flubendiamide @ 0.2 ml/L, or Spinosad @ 0.3 ml/L or Chlorantraniliprole @ 0.3ml/l or Spinetorum @ 1ml/l.
  - For *S. litura*, additional effective molecules include Novaluron @ 1 ml/L

Seedling Blight (*Phytophthora parasitica*)

Symptoms: The disease starts as circular, dull-green patches on the cotyledon leaves of seedlings. These patches spread, leading to rotting. In grown-up plants, infection appears on young leaves, then spreads to the petiole and stem, causing black discoloration and heavy defoliation.

Favorable conditions: Continuous rains, cool weather (20–25°C), and waterlogging in low-lying fields.

Management:

- Avoid sowing in poorly drained or low-lying soils.
- Treat seeds with Thiram or Captan (3 g/kg) before sowing.
- Remove and destroy infected plant residues.
- Drench the soil with Metalaxyl (2.5–3 g/L) or Copper oxychloride (3 g/L) when disease appears.

Wilt (*Fusarium oxysporum*)

Symptoms: In seedlings, cotyledon leaves turn dull green, then wither and die. In mature plants, leaves turn yellow, become brittle, and drop, leaving only a few leaves at the top. Stems of diseased plants show vascular discoloration, and white fungal growth can be seen inside. Affected plants look weak and stunted.

Favourable conditions: Monocropping of castor and sowing of infected seed increase incidence.

Management:

- Follow **crop rotation** with non-host crops.
- Use **healthy, treated seed**: Thiram (3 g/kg), Carbendazim (2 g/kg), or bioagent ***Trichoderma viride* (10 g/kg).**
- Apply ***Trichoderma viride*** (2 kg talc formulation mixed with 100 kg FYM, incubated 15 days) to the soil before sowing.
- Drench affected plants with Copper oxychloride (3 g/L) to check further spread.

Gray Mold (*Botryotinia ricini*)

Symptoms: This disease mainly attacks spikes, flowers, and capsules. Infected flowers rot and are covered with gray, ash-colored fungal growth. Capsules rot, shed off, and infected spikes become sterile. In severe cases, cottony white fungal growth later turns gray due to sporulation, and yellowish droplets ooze from infected tissues.

Favourable conditions: Continuous rains, night temperature below 22°C, and high humidity.

Management:

- Adjust sowing time so that flowering and maturity do not coincide with heavy rains.
- Maintain wider spacing (90 × 60 cm) for good aeration.
- Remove and destroy diseased spikes.
- Prefer varieties with non-spiny capsules and loose inflorescence.
- Seed treatment with Carbendazim (2 g/kg) before sowing.
- Preventive sprays of Carbendazim (1 g/L), Propiconazole (1 ml/L), or Thiophanate methyl (1 g/L) before cyclonic rains, followed by another spray after rains.
- Apply 20 kg urea + 10 kg muriate of potash after removing diseased spikes to promote healthy spike growth.

Conclusion

Rainy-season pests and diseases significantly threaten castor yields. Timely **integrated pest and disease management (IPDM)** combining cultural, biological, and need-based chemical measures ensures sustainable crop protection, higher productivity, and reduced losses in rainfed castor farming.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Carbon Sequestration in Horticultural Crops

[1]Sitaram Saran, [2]Jinti Mani Sharma, [3]Payal Paul, Pardeep and *Pranava Praanjal

[1,2,3]M.Sc. Vegetable Science, *Ph.D. Vegetable Science
Department of Vegetable and Spice Crops, Uttar Banga Krishi Viswavidyalaya
Pundibari, Cooch Behar 736165, West Bengal
*Correspondence - pranavapraanjal71@gmail.com

INTRODUCTION

Climate change has always been a part of Earth's natural history. It can happen over decades or even thousands of years. However, the current rate of warming is a big concern because scientists say there is over a 95% chance that human activities since the mid-1900s are the main cause.

Some greenhouse gases (GHGs) are needed to keep our planet warm enough to live on, but right now, the Earth is warming about ten times faster than it did after the ice ages. The main reason for this fast warming is the large amount of GHGs in the air caused by humans. Carbon dioxide (CO2) is the most common and long-lasting of these gases.

Studies show that the Earth's average temperature has gone up by about 1°C since the late 1800s, mostly because of the extra CO2 in the air. CO2 alone is responsible for almost half of the global warming. It gets into the air naturally from things like volcanic eruptions and breathing soil, but human activities like burning fossil fuels, cutting down forests, and changing how land is used have made the problem much worse. Since the industrial revolution, CO2 levels in the atmosphere have increased from 280 parts per million (ppm) to 400 ppm—mostly due to industries.

Sustainable farming in vegetable production (also called olericulture) is based on the idea of meeting today's needs without hurting the ability of future generations to meet theirs. Sustainable agriculture focuses on keeping the environment healthy, making sure farming stays profitable, and treating people fairly.

This kind of farming helps protect biodiversity—the variety of life in ecosystems—and avoids using harmful chemicals, genetically modified seeds, and methods that damage soil and water. Instead, it uses smart farming practices like rotating crops, reducing how often the soil is tilled, and managing animals on pastures to save resources and keep the land healthy. The goal is to grow food in a way that protects the land for the future.

There is now more demand for practical and affordable ways to lower CO2 in the air while also improving soil health. One promising method is carbon sequestration. This means capturing CO2 from the air and storing it in places like plants, soil, oceans, and other natural areas. It helps slow down climate change and improves soil quality, which supports better plant growth.

1. Carbon Capture and Sequestration: Mechanisms

This flowchart illustrates the carbon flow and energy dynamics in an ecosystem, particularly focused on plant productivity, decomposition, and soil biomass accumulation. Here's a step-by-step explanation of the process:

1. Gross Primary Production (GPP): - Total amount of carbon fixed by plants through photosynthesis.
Pathways: A portion is lost to Dark Respiration (energy used by plants in the absence of light).
2. Net Photosynthesis: - GPP minus dark respiration gives the Net Photosynthesis.
Part of this is lost through Plant Respiration (energy used for maintenance and growth).
3. Net Primary Production (NPP): - NPP = Net Photosynthesis - Plant Respiration. This is the energy available for plant growth and for other trophic levels.
4. Live Biomass Accumulation: -NPP contributes to live plant biomass. Two fates: Becomes Litter and Exudates (shed leaves, roots, secretions). Consumed by microbes (Microbial Consumption).
5. Microbial Consumption: -Microbes decompose plant material, using some carbon for:
Respiration (releasing CO_2). Producing Net Secondary Production (microbial biomass).
6. Net Secondary Production: - Part of microbial biomass contributes to Live Soil Biomass Accumulation in Plants (via symbiosis, e.g., mycorrhizae). Lost to Predation by other soil organisms.

7. Soil Organic Matter: -Litter and exudates not consumed by microbes become part of soil organic matter. Contributes to Long-term soil carbon storage. Feeding back into Net Ecosystem Production (NEP).

8. Net Ecosystem Production (NEP): - Final measure of carbon retained in the system.

NEP = NPP - (plant + microbial respiration).

Indicates whether the ecosystem is a carbon sink or source.

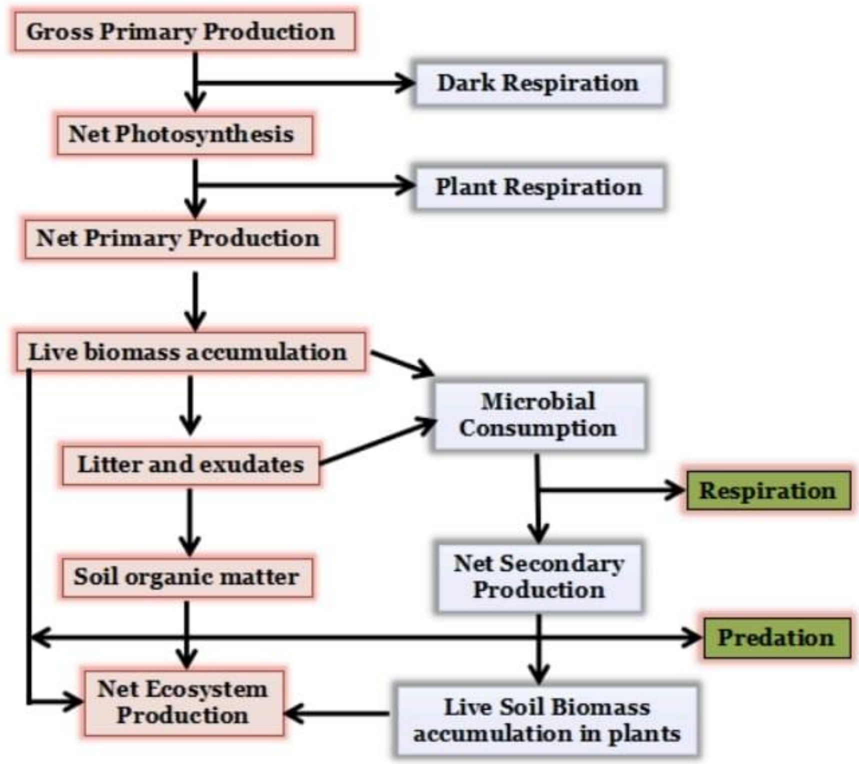
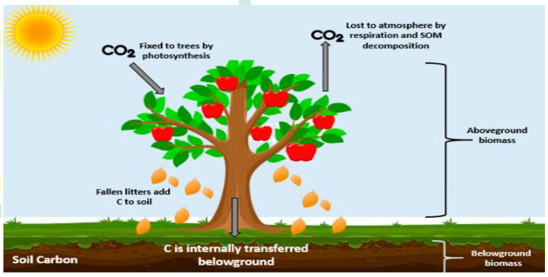


Fig 1. Mechanism of carbon sequestration

2. Process of carbon sequestration in plants.

Plants absorb CO_2 during photosynthesis and convert it into carbohydrates (biomass)

- Above-ground carbon (leaves, stems)
- Below-ground carbon (roots, root exudates)
- Plant roots respire using o_2 and producing co_2 as a byproduct
- Plant roots respire using o_2 and producing co_2 as a byproduct



Stout *et al., (2016)*

Influencing Factors for Soil Organic Carbon Sequestration

Soil carbon sequestration plays a crucial role in reducing the impact of climate change, improving soil fertility, and supporting sustainable agricultural practices. A number of factors affect the soil's ability to store carbon, such as soil characteristics, land management techniques, climatic conditions, and kinds of vegetation. Quantifying the exact proportion of each component that influences soil carbon sequestration is difficult because of the intricate inter play between these factors and the diversity across diverse ecosystems and management approaches.

Why Horticultural Crops for Carbon Sequestration?

Approximately 120 gigatons (Gt) of carbon are fixed annually by photosynthesis in plants worldwide, with horticulture crops making a major contribution. Perennial fruit trees, plants, gardens, etc., contain 25–100 times more carbon in their biomass than agricultural fields. Therefore, unoccupied and wastelands might be assigned to permanent. Therefore, unoccupied and wastelands might be assigned to permanent horticulture systems rather than agricultural or agroforestry crops. There are important reasons for considering the horticulture area as a prime

ISSN : 3048 - 989X

source to sequester carbon and offset GHGs emission. They are the following: horticulture systems rather than agricultural or agroforestry crops. There are important reasons for considering the horticulture area as a prime source to sequester carbon and offset GHGs emission. They are the following:

(i) Perennial Growth: Many horticultural crops are perennial, meaning they live for multiple years. This extended growth period allows them to accumulate more biomass and contribute more organic matter to the soil over time, increasing carbon sequestration potential. The biomass carbon content in these crops generally falls within the range of 40–50% of their dry weight. For example, an apple orchard covering one hectare may normally capture around 20–30 tonnes of CO_2 annually, while a tomato field of the same size can sequester around 10–15 tonnes. of 40–50% of their dry weight. For example, an apple orchard covering one hectare may normally capture around 20–30 tonnes of CO_2 annually, while a tomato field of the same size can sequester around 10–15 tonnes.

Factor	Percentage Contribution	Description
A. Soil Properties (30%)		
Soil Texture	15%	Clay-rich soils can sequester carbon by protecting organic materials from degradation.
Soil Structure		Well-aggregated soils facilitate organic matter-stabilizing microenvironments.
Soil pH	5%	Optimal pH (6–7) promotes microbial activity and nutrient availability, improving sequestration.
Soil Moisture	10%	Moist soil is necessary for plant development and microbial activity, which add carbon and stabilize soil.
Soil Temperature		Moderate temperatures enhance microbial activity and carbon stabilization, whereas severe temperatures hinder both.
B. Land Management Practices (40%)		
Tillage Practices	10%	Conservation tillage increases soil carbon by 57% over conventional tillage.
Crop Rotation and Diversification	10%	Cover crop rotations boost soil organic carbon by 20% over monocultures.
Organic Amendments	10%	By adding organic matter like compost and manure, soil carbon content increases. Organic additives boost soil carbon reserves over time.
Agroforestry	10%	Adding trees to agricultural areas increases biomass and soil carbon sequestration. Agroforestry systems can store 1.5 Mg C ha^{-1} yr^{-1}.
Perennial Cropping Systems		Deep root systems help perennial crops like switchgrass and miscanthus store soil carbon. Perennial crops trap carbon well on marginal landscapes.
C. Climate Conditions (20%)		
Temperature and Precipitation	15%	Climate substantially impacts soil carbon sequestration. Warm, wet temperatures boost plant production and soil carbon.
Extreme Weather Events	5%	Droughts, floods, and storms damage soil structure, vegetation, and erosion, reducing soil carbon sequestration.
D. Vegetation Types (10%)		
Grasslands	4%	Grasslands are significant carbon sinks due to their extensive root systems and continuous ground cover.
Forests	4%	Forest biomass and soil store much of carbon. Forest soils may store up to 2.0 Mg C ha^{-1} yr^{-1}, depending on species mix, age, and management approaches.
Wetlands	2%	The slow decomposition, makes wetlands one of the best carbon sequestration habitats. Wetlands, such as peatlands, trap up to 5.5 Mg C each year.

(ii) Root Structure: Compared to annual crops, the root systems of horticultural plants are often more widespread and penetrating. These deeper roots can store carbon deeper in the soil, reducing its vulnerability to rapid decomposition.

(iii) Continuous Ground Cover: This is maintained by perennial horticulture crops, which lower soil erosion and avoiding carbon loss from the topsoil. It also helps maintain soil structure and organic matter content.

(iv) Reduced Tillage: Many horticultural systems use reduced or no-till practices, which minimize soil disturbance and carbon loss through oxidation. Reduced tillage also promotes the accumulation of organic matter, fostering a healthier soil ecosystem.

(v) Diverse Cropping Systems: Horticultural systems often involve a diverse range of plant species and crop rotations. This diversity enhances soil health by supporting a variety of soil microorganisms that contribute to organic matter decomposition and carbon storage. plant species and crop rotations. This diversity enhances soil health by supporting a variety of soil microorganisms that contribute to organic matter decomposition and carbon storage.

(vi) Organic Matter Inputs: The organic matter content of soil may be increased by horticultural practices such as the use of cover crops, organic mulches, and compost. This organic matter serves as a carbon source and contributes to long-term carbon sequestration.

(vii) Agroforestry and Orchards: Some horticultural systems, like agroforestry and orchards, involve planting trees alongside crops. Due to their vast biomass and extensive roots, trees are very adept at carbon sequestration. Agroforestry systems have the capacity to capture and store 3–5 tonnes of carbon dioxide per hectare year, which is much more than the amount sequestered by monoculture systems.

(viii) Urban and Peri-urban Settings: Horticultural practices are often integrated into urban and peri-urban areas, where they can convert unused spaces into carbon sinks. Urban agriculture contributes to carbon sequestration, improves air quality, and enhances local food security. urban and peri-urban areas, where they can convert unused spaces into carbon sinks. Urban agriculture contributes to carbon sequestration, improves air quality, and enhances local food security.

(ix) Longer Harvest Cycles: Horticultural crops typically have longer harvest cycles compared to annual crops. This means that the fields are disturbed less frequently, reducing carbon loss from the soil.

(x) Soil Health Benefits: Horticultural practices that focus on soil health management also improve carbon sequestration. Healthy soils with good structure and microbial diversity enhance carbon storage capacity.

Carbon Sequestration Examples of vegetable crops

The majority of vegetable crop operations, including those that are produced on dry ground, under irrigation, or in arid conditions, discourage the use of conservation tillage due to diverse rotations and specialized management techniques in the field. There are, however, few research studies on using cover crops in vegetable cultivation to increase soil carbon storage. Increasing crop frequency and using high residue crops are two management strategies that are recommended for vegetable systems to improve SOC. Alternately, soil tillage improves plant water usage efficiency, and the use of mulches may minimize soil carbon loss. Incorporation of legumes (cluster bean, cowpea, pea, French bean, lab-lab, etc.) can be effective for allocating a higher plant biomass carbon percentage to the belowground sequestration of soil carbon. Potadar and Patil observed that the carbon sequestration potential of moringa was about 117.44 kg/tree. It was found that improved crop land practices could enhance the sequestration of SOC rates from 0.1 to 1 tonne of carbon per ha per year with diminishing accumulation rates as the soil approaches a new equilibrium. Vegetable biomass, including the leftover leaflet, can be converted into biochar and then incorporated into soils to retain carbon for a longer period of time.

8. Challenges in Monitoring Carbon Sequestration: -

However, there are several opportunities to use the carbon stock and sequestration capacity in the soil of different ecosystems, but there are a number of obstacles to overcome stated below to make it happen in practice:

(i) Measurement and Verification: It is challenging, costly, and time-consuming to measure the carbon stored in the soil. Due to sample mistakes, small-scale variability, and uncertainties in measurement and analysis, it is much more challenging to identify changes inside the 10% range. The average yearly increase in soil carbon stock is just 0.25 to 1.0 tonne per hectare. It is difficult to account for little changes in soil carbon at various scales due to challenges in methods, such as verification, sampling, monitoring, and depth. Even when these small changes (loss or gain) are detected, it is not very easy to link such changes in land use or management practices in a given context. The soil can only hold and store carbon for a limited amount of time before it reaches a steady state.

(ii) Carbon pools: In the context of soil carbon sequestration, carbon is partitioned into distinct pools, each characterized by varying residence times within the ecosystem, as outlined by Abdullahi and his co-workers. The first pool is the passive, refractory, or recalcitrant pool, housing organic carbon with an extended residence duration spanning decades to even millennia. This carbon is notably resilient to decomposition due to its intricate molecular structure. Second, the active, fast, or labile pool contains carbon susceptible to swifter decomposition, resulting in a shorter residence span ranging from a mere day to a full year.

(iii) Permanence: Another problem with storing carbon in the soil is that it does not stay there forever. Carbon that has been stored in the soil can easily be released back into the air through mineralization or decomposition. This is the rationale for thinking of carbon sequestration as a temporary solution to reduce atmospheric carbon. Numerous land use, climate, and management variables influence the loss of carbon.

(iv) Separation: It is challenging to separate and isolate the diverse forms of carbon that are sequestered in the soil as a consequence of land use or management activities that occur naturally. According to the separation principle, management action or natural factors may stop carbon sequestration or greenhouse gas emissions. Therefore, techniques that can distinguish between carbon that is naturally sequestered and carbon that is trapped by human management are required.

Conclusion

Despite their significant capacity for carbon sequestration and climate change mitigation, horticultural crops have not fully utilized this potential. Perennial horticultural systems possess vast root structures, maintain continuous ground cover, and have long growth seasons, which provide notable benefits compared to annual crops. These systems have the ability to improve levels of SOC, with research showing a gradual rise of 20–50% in SOC over time as compared to annual systems. The enhancement is propelled by the process of photosynthesis, the release of substances from the roots known as root exudates, and the addition of organic materials. Utilizing methods such as crop rotation, intercrop ping, cover cropping, and companion planting may enhance plant material yield by 15–30% and enhance soil quality, resulting in a possible yearly increase in soil carbon storage of 2–5 tonnes of carbon per hectare. Improved monitoring techniques and models can help overcome the barriers associated with determining and verifying carbon sequestration, such as measurement complexity, carbon pool distinction, and permanence. Significant quantities of atmospheric CO_2 can be absorbed by horticultural crops; perennial systems have the capacity to sequester 4–7 tonnes of CO_2 per hectare annually.

References:

Ilakiya, T., Parameswari, E., Swarnapriya, R., Yazhini, G., Kalaiselvi, P., Davamani, V., Singh, S., Vinothini, N., Dharani, C., Garnepudi, S. L., & Ajaykumar, R. (2024). Unlocking the carbon sequestration potential of horticultural crops. *Journal of Carbon Research, 10*(1), Article 65.

Al-Sheikh, A., Delgado, J. A., Barbarick, K., Sparks, R., Dillon, M., Qian, Y., & Cardon, G. (2005). Effects of potato–grain rotations on soil erosion, carbon dynamics and properties of rangeland sandy soils. *Soil and Tillage Research, 81*(2), 227–238. https://doi.org/10.1016/j.still.2004.09.005

Stout, B., Lal, R., & Monger, C. (2016). Carbon capture and sequestration: The roles of agriculture and soils. *International Journal of Agricultural and Biological Engineering, 9*(1), 1–8. 4.

Six, J., Frey, S. D., Thiet, R. K., & Batten, K. M. (2006). Bacterial and fungal contributions to carbon sequestration in agroecosystems. *Soil Science Society of America Journal, 70*(2), 555–569. https://doi.org/10.2136/sssaj2004.0347

Xia, S., Song, Z., Van Zwieten, L., Guo, L., Yu, C., Wang, W., & Wang, H. (2022). Storage, patterns and influencing factors for soil organic carbon in coastal wetlands of China. *Global Change Biology, 28*(18), 6065–6085. https://doi.org/10.1111/gcb.16337

Kaliappan, S. B., Gunasekaran, Y., Smyrna, R., & Meena, R. S. (2019). Soil and environmental management. In *Sustainable management of soil and environment* (pp. 1–27). Springer. https://doi.org/10.1007/978-981-13-6830-1_1

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Current Challenge to Face Environmental Pollution

Firdous Ashraf

Ph. D. Scholar, Division of Soil Science, Faculty of Horticulture, Sher-e-Kashmir University of Agricultural Sciences & Technology of Kashmir

The world today is facing scores of problem and greatest among them is the problem of environmetal pollution. Enviromental pollution today has become a buzz word. The biotic (plants, animals etc.) and abiotic components (land, air, water etc.) and their interaction constitute our enviroment. If any change occurs in these components would lead to disaster in the world.

Industrialization gives rise to industries and factories, pollute our environment by the removal of harmful waste effluents and heavy metals. These harmful wastes received by water bodies from these industries and factories not only affects the water quality but also disturbs aqua-ecosystem of phytoplankton and zooplankton. Another effect occur due to water pollution is eutrophication, due to this it is found that death rate of pisces increase because eutrophication process decreases the concentration of oxygen in water. If concentration of heavy metals increase in irrigation water causes soil pollution which finally affects the plant growth and development.

From industries and factories, harmful gases are removed and goes into atmosphere leads to air pollution and then production of acid rain, ozone layer depletion like processes occurs. Luxurious use of chemical fertilizers or inorganic fertilizers not only pollute our soil and water (nitrate pollution) but also makes the soil sick and decrease its fertility and productivity capacity. So we should use biofertilizers inplace of these toxic chemical fertilizers, which are helpful to improve physical, chemical and biological properties of soil.

Deforestation i.e indiscriminate cutting down of trees causes ecological imbalance in our environment. Especially the global warming and green house effect occur due to ecological imbalance when concentration of carbon dioxide increases in atmosphere, and finally melting of glaciers occurs due to global warming and then there is a threat of floods as the water level increases in water bodies. So it is rightly said that “Afforestation is life but deforestation is death.” One of the great saint of kashmir: Shiekh Noor ud- Din wali’s (locally call Nund Reshi in kashmir) famous saying regarding protection of forests is “Ann poshi teli yeli wan poshi” means food will thrive only till the wood survive.

In nutshell inorder to live on this planet we should utilize the components of environment carefully and in a proper way and everyone should follow three R’s to save our environment i.e reduce, reuse and recycle.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Digital Agronomy: Mobile Apps and AI for Farmers' Decision-Making in India

Dr. Pragya Tiwari

Indira Gandhi Krishi Vishvavidyalaya, Raipur (Chhattisgarh)

1. Introduction

Agriculture continues to be the backbone of the Indian economy, employing over 42% of the workforce and contributing about 18% to the national GDP. Yet, farming in India remains highly vulnerable to risks such as erratic monsoons, climate change, pest outbreaks, and volatile market prices. Traditional agronomy based on seasonal experience, extension services, and government advisories often falls short of addressing real-time challenges faced by small and marginal farmers.

This is where digital agronomy comes into play. With the spread of smartphones and affordable internet in rural areas, digital tools are revolutionizing how farmers make decisions. By combining mobile apps, artificial intelligence (AI), machine learning (ML), remote sensing, and big data analytics, digital agronomy empowers farmers to adopt data-driven, timely, and cost-effective strategies.

India's digital transformation in agriculture is not just a technological leap—it is a socio-economic necessity.

2. Understanding Digital Agronomy

Digital agronomy can be defined as the application of digital technologies to collect, analyze, and apply agricultural data for better crop and farm management. It integrates:

- Mobile Applications: Provide real-time advisories on weather, soil, crop management, and markets.
- AI & ML Algorithms: Analyze massive datasets to generate predictions and customized recommendations.
- Decision Support Systems (DSS): Offer farm-specific guidance on sowing, irrigation, fertilizer application, and pest control.
- Remote Sensing & GIS: Use satellite and drone imagery to assess crop health and soil conditions.
- Big Data Analytics: Combine climate, soil, market, and farm-level data for predictive insights.

In simple words, digital agronomy brings science to farmers' fingertips in a user-friendly format.

3. Growth of Mobile Apps in Indian Agriculture

With over 750 million smartphone users and increasing rural internet penetration (46% in 2023), mobile apps are the most accessible form of digital agronomy. Some popular examples include:

Government-backed Apps

- Kisan Suvidha: Offers weather forecasts, input dealer details, market prices, and plant protection advice.
- mKisan SMS Portal: Delivers over 1,000 crore messages annually in regional languages with crop advisories.
- Pusa Krishi App (ICAR-IARI): Shares information about improved seed varieties, soil management, and new technologies.

Private & Startup Initiatives

- Plantix (by PEAT, Germany): Farmers can upload images of crop diseases; AI provides instant diagnosis and treatment advice. Widely used in Maharashtra and Telangana.
- AgriApp: Provides crop advisory, weather updates, and an online marketplace for inputs.
- Iffco Kisan App: Combines AI, satellite imagery, and expert advice for farm management.
- NinjaKart & DeHaat: Go beyond advisory by connecting farmers to input suppliers and buyers.

Case Study:

In 2021, during a pest outbreak in cotton fields of Vidarbha (Maharashtra), Plantix app users were able to identify pink bollworm early and adopt timely pest management measures, reducing crop losses by nearly 25% compared to non-users.

4. Role of Artificial Intelligence in Indian Agronomy

AI is the brain of digital agronomy. It transforms raw data into actionable insights.

- Weather & Crop Prediction: AI models use historical weather data and soil information to suggest the best sowing windows.
- Disease & Pest Detection: Apps like Plantix and Fasal AI use image recognition to detect crop issues in seconds.
- Nutrient Management: AI-driven tools like Nutrient Expert (developed by CIMMYT & IPNI) recommend balanced fertilizer use tailored to soil type.
- Water Use Efficiency: AI-powered irrigation systems calculate the exact amount of water needed, reducing wastage by up to 30–40%.
- Market Price Forecasting: AI-based tools predict demand and price trends, helping farmers sell produce at the right time.

Success Example – Microsoft & ICRISAT Project:

In Andhra Pradesh, Microsoft developed an AI Sowing App that advised groundnut farmers on optimal sowing dates based on weather patterns. Farmers who followed AI recommendations recorded a 30% increase in yield and higher profits.

5. Benefits of Digital Agronomy

Digital agronomy is proving to be a game-changer in Indian agriculture:

1. Improved Productivity: Precision farming ensures higher yields per hectare.
2. Input Efficiency: Farmers save 15–25% on fertilizers and pesticides through accurate recommendations.
3. Water Conservation: Smart irrigation apps help save scarce water resources.
4. Risk Management: Early warnings on pests, diseases, and extreme weather reduce crop losses.
5. Market Access: Digital platforms connect farmers directly with buyers, ensuring better prices.
6. Inclusivity: Women and young farmers find digital tools easier to access compared to traditional extension.
7. Sustainability: Promotes eco-friendly practices by reducing chemical overuse.

6. Challenges in Adoption

Despite strong potential, adoption is not uniform across India. Challenges include:

- Digital Divide: Only 1 in 3 rural households owns a smartphone.
- Language & Literacy Barriers: Many apps are not available in all regional languages.
- Awareness Gap: Farmers may be hesitant or unaware of the benefits of digital tools.
- Affordability: Premium AI services, drones, and IoT devices are expensive for smallholders.
- Data Privacy Concerns: Farmers' personal and farm data security must be ensured.

Example:

In Bihar, although DeHaat app reached thousands of farmers, low digital literacy among older farmers limited its adoption. Youth, however, embraced it more readily.

7. Policy and Institutional Support

The Government of India is actively promoting digital agronomy through policies and programs:

- Digital Agriculture Mission (2021–25): Focuses on using AI, blockchain, and drones for agriculture.
- National e-Governance Plan in Agriculture (NeGPA): Provides ICT-based solutions to farmers.
- Agri-Stack Initiative: Creation of a unified farmer database for customized advisory.
- Startup Support: Agri-tech startups are encouraged through incubators like NAARM-ABI, MANAGE, and NABARD support.

8. Future Prospects of Digital Agronomy in India

The future looks promising, with innovations on the horizon:

- AI + IoT Integration: Soil sensors, drones, and satellite-based crop monitoring.
- Blockchain: Transparent supply chains and fair trade practices.
- Hyper-localized Advisory: Farm-level personalized insights for each farmer.
- Voice-based AI Assistants: Advisory in local dialects for illiterate farmers.

- Climate-smart Agronomy: Digital tools to adapt cropping patterns to climate change.

By 2030, India's agri-tech sector is projected to be worth $24 billion, with digital agronomy playing a central role in making farming profitable and sustainable.

9. Conclusion

Digital agronomy is more than a technological revolution—it is a farmer empowerment movement. With mobile apps and AI-driven tools, farmers are no longer dependent solely on intuition or delayed advisories. Instead, they can access real-time, scientific, and personalized solutions to make smarter decisions.

While challenges of affordability, awareness, and digital literacy must be addressed, the long-term benefits are undeniable. With supportive policies, farmer-friendly apps, and collaborative efforts between government, startups, and research institutions, digital agronomy can help India achieve food security, climate resilience, and higher farmer incomes.

As the saying goes:

"The future farmer will be a data-driven decision maker, not just a cultivator."

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

The Role of Farmers' Varieties in Genetic Resource Management and Food Security

***Bhoirab Gogoi[1], Shourov Dutta[2], Prabhat Baruah[3], Puja Basumatary[4], Prasanna Kumar Pathak[5], Sanjoy Borthakur[6] and Manoranjan Neog[7]**

[1]Subject Matter Specialist (Horticulture), KVK, Jorhat,
Assam Agricultural University, Teok-785112
[2]Subject Matter Specialist (Horticulture), KVK, Karbi Anglong,
Assam Agricultural University, Diphu-782462
[3]Subject Matter Specialist (Animal Science), KVK, Jorhat,
Assam Agricultural University, Teok-785112
[4]Subject Matter Specialist (Horticulture), KVK, Kokrajhar,
Assam Agricultural University, Gossaigaon-783360
[5]Dean, College of Agriculture,
Assam Agricultural Univeristy, Jorhat-785013
[6]Senior Scientist and Head, KVK, Jorhat,
Assam Agricultural University, Teok-785112
[7]Directorate of Extension Education,
Assam Agricultural Univeristy, Jorhat-785013
*Corresponding Email: bhoirab.aau@gmail.com

Abstract

Farmers' varieties, also known as traditional, landrace, or indigenous crop varieties, have played a foundational role in the development of agriculture since the dawn of domestication. These varieties, selected and maintained by generations of farmers, embody rich genetic diversity and adaptive traits suited to local agro-ecological and cultural conditions. In the modern context of climate change, soil degradation, pest resistance, and food security challenges, these varieties are resurging as vital assets. This chapter explores the significance, conservation, utilization, and policy support for farmers' varieties in shaping sustainable and resilient agriculture systems. It also discusses the interplay between farmers' knowledge and scientific breeding, legal frameworks such as the Protection of Plant Varieties and Farmers' Rights Act (PPV&FRA), and case studies from India and especially Assam.

Introduction

Agriculture, as we know it today, has evolved over millennia through the meticulous selection and propagation of plants by farmers. The earliest cultivators began domesticating wild species, resulting in what are now known as farmers' varieties—landraces that have co-evolved with human cultures and environments. These varieties, unlike modern hybrids, are genetically diverse and carry traits like drought tolerance, disease resistance, and nutrient efficiency that are crucial for sustainable agriculture. They also represent the cultural identity, dietary practices, and ecological wisdom of farming communities.

Defining Farmers' Varieties

Farmers' varieties refer to those crop varieties that have been developed, conserved, and improved by local farmers through traditional knowledge and practices. The Protection of Plant Varieties and Farmers' Rights Act (2001) of India defines farmers' varieties as:

"A variety which has been traditionally cultivated and evolved by the farmers in their fields or is a wild relative or landrace of a variety about which the farmers possess the common knowledge."

Unlike commercial hybrids or GM crops, farmers' varieties are open-pollinated and allow seed saving, enabling continued selection and evolution at the grassroots level.

Genetic Diversity and Climate Resilience

1. Adaptive Traits

Farmers' varieties are reservoirs of genetic traits that enable crops to adapt to diverse and extreme conditions such as:

- Drought (e.g., 'Kattucumbu' millet in Tamil Nadu)
- Salinity (e.g., 'Pokali' rice in Kerala)
- Floods (e.g., 'Deepwater' rice varieties in Assam and Bihar)
- Pests and diseases

Their genetic heterogeneity makes them inherently resilient and adaptable, ensuring yield stability under marginal conditions.

2. Importance in Crop Improvement

Genetic diversity from farmers' varieties is a critical input for modern breeding programs. Many high-yielding or resistant cultivars have been developed by incorporating traits from landraces. For instance, the famous IR8 rice variety, dubbed the "miracle rice," was developed using genes from traditional varieties.

Reference: Ceccarelli, S. (2012). "Plant breeding with farmers: a technical manual." FAO.

Role in Sustainable Agriculture

Farmers' varieties contribute significantly to sustainable agriculture by enhancing agro ecological balance and supporting resilient food systems. These varieties are naturally adapted to local climates and soils, which helps maintain biodiversity and reduce the reliance on chemical inputs. Their cultivation supports traditional mixed cropping systems, improves soil health, and helps control pests and diseases organically.

Furthermore, farmers' varieties are often low-input crops, requiring fewer fertilizers, pesticides, and water. This makes them economically viable and environmentally friendly, especially for small and marginal farmers. Their continued use supports seed sovereignty and the conservation of traditional knowledge, both of which are crucial for long-term sustainability. By preserving these varieties, farmers act as stewards of genetic resources that are vital for climate resilience and future food security, making them ideal for smallholders and organic farming. Their compatibility with local agronomic practices reduces ecological footprints and production costs.

Cultural and Nutritional Significance

Farmers' varieties are often associated with specific food cultures and traditional diets. For example:

- 'Chakhao' (black rice) in Manipur is known for its high antioxidant content.
- Traditional millets like ragi and foxtail millet are valued for their high calcium, iron, and fiber content.

These crops play a vital role in dietary diversity, nutrition security, and cultural preservation.

The nutritional superiority of traditional varieties is evident when compared with commercial hybrids. For instance, traditional millets often contain higher levels of micronutrients such as iron, zinc, and calcium. Below is a sample comparison:

Crop Type	Variety Type	Protein (%)	Iron (mg/100g)	Calcium (mg/100g)	Fiber (%)
Finger Millet	Traditional	7.3	3.9	344	3.6
Finger Millet	Hybrid	6.5	2.4	270	2.1
Black Rice	Traditional (Chakhao)	9.5	4.5	90	2.5
White Rice	Hybrid	6.8	1.2	10	0.3

Reference: Padulosi, S., et al. (2011). "Agrobiodiversity and the poor: Promoting neglected and underutilized species for food security." Bioversity International.

Farmers' Rights and Legal Recognition

The PPV&FRA (2001) is a pioneering legislation that recognizes the rights of farmers to:

- Save, use, exchange, and sell farm-saved seeds
- Register their own varieties
- Benefit from the commercial use of their varieties (Benefit Sharing)

Conservation Initiatives

1. Community Seed Banks

Farmers' groups and NGOs have established seed banks to preserve and share traditional varieties. Examples include:

- Navdanya's community seed networks
- MSSRF's Community Agrobiodiversity Centres

2. On-Farm Conservation

On-farm conservation by cultivating traditional varieties in situ allows ongoing selection and evolution, adapting to changing climates.

3. National Gene Bank Support

Institutions like the National Bureau of Plant Genetic Resources (NBPGR) maintain ex situ collections of landraces.

Case Studies: Reviving Farmers' Varieties in Assam

Assam is a hotspot of agrobiodiversity with a wide range of traditional crop varieties. Here are notable examples:

- **Bao Dhan (Floating Rice):** Cultivated in flood-prone districts like Dhemaji and Majuli, this deepwater rice is flood-resilient, organically grown, and provides high straw yield for livestock.
- **Kola Joha and Tulaipanji (Aromatic Rice):** These indigenous aromatic rice types from Jorhat and Golaghat are premium quality grains with growing demand in niche markets.
- **Tribal Pulses (Karbi Anglong):** Local landraces of cowpea, black gram, and French beans maintained by Karbi tribes are used in mixed cropping and soil health.
- **Traditional Millets (Dima Hasao and Kokrajhar):** Finger millet, foxtail millet, and Job's Tears are being revived by tribal farmers and included in nutrition programs.
- **Indigenous Leafy Greens (Upper Assam):** Local varieties of mustard greens, spinach, and roselle (Lai Xaak, Paleng Xaak) are being promoted in nutrition gardens for women and children.
- **Bhot Jolokia (Ghost Pepper) and Brinjal Landraces:** Indigenous chillies and eggplants are being conserved for their pest resistance and market value.

References: KVK Dhemaji, KVK Jorhat, NABARD-Assam Reports, North East Network, AAU Annual Reports.

Challenges in Promoting Farmers' Varieties

Despite their ecological, cultural, and nutritional value, farmers' varieties face significant challenges that hinder their widespread adoption and conservation. One major issue is the gradual replacement of traditional varieties with high-yielding hybrids promoted through industrial agriculture and market-driven seed systems. Additionally, there is limited access to formal markets and a lack of support for farmer-led seed enterprises. Traditional knowledge associated with these varieties is eroding due to generational shifts and the influence of modern practices. Furthermore, the absence of robust documentation and registration mechanisms restricts the recognition and protection of farmers' intellectual contributions. Lastly, inadequate policy incentives and institutional backing make it difficult for farmers to sustain these varieties economically.

Policy and Institutional Support

Robust policy and institutional frameworks are essential to promote and protect farmers' varieties. At the national level, initiatives such as the National Mission on Sustainable Agriculture (NMSA) and Rashtriya Krishi Vikas Yojana (RKVY) support the conservation and promotion of agrobiodiversity, including farmers' varieties. Krishi Vigyan Kendras (KVKs) play a vital role by facilitating on-farm conservation, seed banks, and training programs.

Internationally, instruments like the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) and the Convention on Biological Diversity (CBD) advocate for farmers' rights, equitable benefit sharing, and the conservation of genetic resources. These treaties help align India's national policies with global biodiversity and food security goals.

Further, the Protection of Plant Varieties and Farmers' Rights Act (2001) provides legal backing for farmers to register, save, and sell seeds of their own varieties, ensuring recognition and incentives for their conservation efforts. Strengthening these institutional mechanisms can empower farmers and ensure the long-term sustainability of traditional crop systems.

Reference: FAO (2009). "International Treaty on Plant Genetic Resources for Food and Agriculture." Rome.

Way Forward

To harness the full potential of farmers' varieties in evolving agriculture, a multipronged strategy must be adopted. First, strengthening in situ conservation through community seed banks, participatory breeding, and farmer field schools will ensure continuous adaptation of these varieties to changing climates. On-farm conservation not only maintains genetic diversity but also empowers local communities through seed sovereignty.

Second, farmer-led research and extension services must be promoted. This includes training programs, capacity building, and decentralized seed production initiatives to enhance the availability and quality of traditional seeds. Third, policy support in the form of legal recognition, subsidies, and inclusion of farmers' varieties in public procurement systems is essential to encourage widespread cultivation.

Fourth, marketing strategies such as Geographical Indication (GI) tags, organic certification, and value chain development can enhance consumer demand and profitability. Fifth, awareness campaigns and educational programs are needed to sensitize the public and young farmers about the nutritional, ecological, and cultural significance of these varieties.

Finally, integrating traditional knowledge with modern scientific research will create synergistic models for resilient and sustainable agriculture. This will ensure that farmers' varieties continue to play a vital role in addressing future food and nutrition security challenges.

Conclusion

Farmers' varieties are not relics of the past; they are the key to a resilient agricultural future. These traditional varieties embody centuries of indigenous knowledge, ecological adaptation, and cultural identity. In the face of increasing climate variability, food insecurity, and ecological degradation, their relevance has never been greater. Through the genetic traits they harbor, such as flood tolerance, pest resistance, and nutrient efficiency, they provide a foundation for future breeding programs and climate-smart agriculture.

The revitalization of these varieties requires a multi-dimensional approach involving policy support, farmer participation, institutional backing, and consumer awareness. Case studies from Assam demonstrate how community efforts, supported by Krishi Vigyan Kendras, NGOs, and local initiatives, have successfully preserved and enhanced these varieties while creating economic and nutritional benefits for rural communities.

A stronger integration of farmers' varieties into modern agricultural systems is not just about crop diversity; it is about equity, sustainability, and self-reliance. As we look ahead, the preservation and promotion of farmers' varieties must be central to any agricultural development strategy aimed at ensuring food sovereignty, climate resilience, and ecological integrity for future generations.

References

Ceccarelli, S. (2012). *Plant breeding with farmers: a technical manual*. FAO.

Padulosi, S., et al. (2011). *Agrobiodiversity and the poor: Promoting neglected and underutilized species for food security*. Bioversity International.

FAO (2009). *International Treaty on Plant Genetic Resources for Food and Agriculture*.

Protection of Plant Varieties and Farmers' Rights Authority. (2024). *Registered Farmers' Varieties Database*. https://www.plantauthority.gov.in

Odisha Millets Mission. (2021). *Annual Programme Report*. Department of Agriculture, Government of Odisha.

NBPGR. (2020). *Annual Report*. National Bureau of Plant Genetic Resources, New Delhi.

KVK Dhemaji Annual Report (2022)

KVK Jorhat Annual Report (2021)

NABARD-Assam State Office Report (2023)

North East Network Publications

Assam Agricultural University Reports (2023)

Rengalakshmi, R., & Nair, K. (2012). "Institutional innovations for sustaining farmers' seed systems: Experiences from India." *IDS Bulletin*, 43(4), 28–35.

Vernooy, R., Shrestha, P., & Sthapit, B. (2015). *Community Seed Banks: Origins, Evolution and Prospects*. Routledge.

Ministry of Agriculture & Farmers Welfare. (2020). *State of Indian Agriculture Report*. Government of India.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Soilless Vegetable Farming for Smart Cities: A Sustainable Path to Urban Food Security

A. Ajay Raja

Research scholar, Department of Vegetable Science, Horticultural College and Research Institute, TNAU, Coimbatore, Tamil Nadu, India - 641 003

Abstract

Urbanization, climate change and the steady decline of arable land are posing enormous challenges to sustainable food production across the globe. By 2050, nearly 70 percent of the global population is expected to live in cities and ensuring access to fresh, nutritious vegetables for these urban populations has become a pressing concern. Traditional soil-based farming is constrained by land degradation, pest pressures, erratic rainfall and water scarcity, making it increasingly inadequate to meet urban dietary demands. Soilless vegetable farming, encompassing hydroponics, aeroponics and substrate-based systems such as cocoponics, has emerged as a scientific and sustainable alternative. These systems optimize the use of water and nutrients, eliminate soil-borne diseases and can be practiced in unconventional spaces such as rooftops, balconies, polyhouses and vertical farms. In India, the Indian Institute of Horticultural Research (IIHR), Bangalore, has pioneered low-cost innovations in soilless farming, notably the development of Arka Fermented Cocopeat (AFC) and Arka Sasya Poshak Ras (ASPR), which have demonstrated high yields, profitability and adaptability under urban and peri-urban conditions. This manuscript reviews the science, technologies, advantages and future prospects of soilless vegetable farming, situating it as a sustainable pathway to food and nutritional security in the context of smart cities.

Keywords: Cocoponics, soilless farming, smart cities, vertical farming, sustainable agriculture, coconut coir.

Introduction

The twenty-first century has witnessed a rapid urban transformation in both developed and developing countries. Increasing urbanization is putting unprecedented pressure on food systems, as urban consumers demand fresh, pesticide-free and high-quality vegetables year-round. Conventional soil-based agriculture, which has been the backbone of human survival for centuries, is struggling to cope with these new demands. Soils are increasingly degraded due to intensive cultivation, nutrient mining and the indiscriminate use of agrochemicals. Water, a vital input for agriculture, is becoming scarce and its inefficient use in conventional systems further aggravates the problem. The adverse impacts of climate change such as erratic rainfall, rising temperatures and frequent droughts, add another layer of complexity to the sustainability of traditional farming. Against this backdrop, soilless vegetable farming is gaining recognition as a futuristic yet practical solution that aligns with the goals of sustainable agriculture and smart urban development.

Soilless farming refers to the cultivation of plants without soil, where water, nutrients and physical support are provided through alternative means such as nutrient solutions or inert substrates. This method is not entirely new; experiments with hydroponics date back to the 1930s, when W. F. Gericke demonstrated the feasibility of growing plants directly in nutrient solutions. Since then, countries like the Netherlands, Israel and Singapore have adopted hydroponics and allied soilless systems on a large scale to address the dual challenges of land scarcity and food demand. In India, soilless farming is still at a nascent stage, but with the rapid expansion of smart cities and the increasing interest of urban entrepreneurs and start-ups in controlled environment agriculture, it is gaining momentum. Importantly, the Indian Institute of Horticultural Research (IIHR) has developed farmer and consumer friendly models of soilless farming, such as cocoponics, that are affordable, sustainable and adapted to Indian conditions.

The Concept and Evolution of Soilless Farming

Soilless farming encompasses several cultivation systems that eliminate the dependency on natural soil. Hydroponics, perhaps the most widely known, involves growing plants in nutrient solutions, either with or without an inert medium. Aeroponics, a more advanced form, keeps plant roots suspended in the air and delivers nutrient mist directly to them, allowing maximum oxygenation. Substrate culture, another major form, grows plants in solid inert media such as cocopeat, perlite, vermiculite or rockwool, which provide mechanical support while the actual nutrients are supplied through fertigation. Aquaponics integrates hydroponics with aquaculture, creating a symbiotic system in which fish waste provides nutrients for plants, while plants purify the water for fish.

Each of these systems has its strengths and limitations. Hydroponics and aeroponics are highly efficient but capital intensive, requiring constant monitoring of nutrient concentrations, pH and water quality. Aquaponics is ecologically appealing but complex to manage, given the need to balance the requirements of both plants and fish. Substrate-based systems, particularly cocoponics using cocopeat, offer a middle path. They combine the efficiency of hydroponics with the affordability and ease of use needed for small-scale urban growers. In tropical countries like India, where coconut is abundantly available, cocopeat-based systems are especially sustainable as they convert agro-waste into a productive substrate.

Relevance of Soilless Farming to Smart Cities

The concept of "smart cities" revolves around integrating technology, sustainability and improved quality of life into urban planning. Food systems are a critical part of this vision and soilless farming offers multiple benefits that align perfectly with the smart city framework. Firstly, soilless farming makes efficient use of space, a scarce commodity in urban areas. Rooftops, balconies, basements and even walls can be transformed into productive spaces for growing vegetables. Secondly, water use efficiency in soilless systems is far superior to soil farming. By re-circulating nutrient solutions and minimizing evaporation losses, these systems can save up to 80–90 percent of irrigation water. Thirdly, soilless farming reduces reliance on pesticides, since soil-borne diseases and nematodes are absent. This not only lowers chemical use but also ensures safer, healthier produce for urban consumers (Lakhiar *et al.*, 2025).

Another important advantage lies in reducing the carbon footprint of food supply chains. Vegetables are highly perishable and transporting them from rural farms to urban centres leads to both quantitative and qualitative losses. Producing vegetables within cities through soilless systems shortens the supply chain, cuts down on food miles and provides consumers with fresher produce. Additionally, soilless farms contribute to urban greening by reducing the heat island effect, improving air quality and adding aesthetic value to urban landscapes. Thus, the integration of soilless farming into smart cities is not only about food security but also about environmental sustainability and improved urban living conditions.

Vegetable Crops and Structures for Soilless Cultivation

A wide range of vegetable crops are well-suited to soilless cultivation owing to their rapid growth, high market demand and adaptability to controlled environments (Fig. 1). Fruiting vegetables such as tomato, cucumber, capsicum, chilli, brinjal, zucchini, gourds and French bean perform exceptionally well under hydroponics and cocoponics systems. Leafy vegetables including spinach, amaranthus, lettuce, coriander, parsley, bok choy and fenugreek are also widely cultivated due to their short crop duration and high yield potential. Exotic vegetables like broccoli, celery and kale find increasing demand in urban markets and are effectively produced in substrate-based systems. Root crops such as radish and carrot have shown moderate success but are less preferred compared to fruiting and leafy types.

Fig. 1. Soilless cultivation of vegetables (Kalaivanan et al., 2022)

For growing these crops, different structures can be adopted depending on space availability and investment capacity. Open terraces and balconies are suitable for household cocoponics and container farming. Polyhouses and shade nets provide partial to full environmental control, protecting crops from excessive heat, rain and pests. Vertical farming units and NFT (Nutrient Film Technique) channels maximize space efficiency in urban settings, making them ideal for leafy greens. Advanced systems such as rooftop greenhouses and climate-controlled vertical farms are being integrated into smart city models, enabling year-round production and enhanced urban food security.

Innovations from ICAR–IIHR: AFC and ASPR

One of the major bottlenecks in adopting hydroponics in India has been its dependence on costly imported inputs such as rockwool and nutrient formulations. Recognizing this challenge, scientists at ICAR–IIHR, Bangalore, developed two breakthrough technologies tailored to Indian conditions: Arka Fermented Cocopeat (AFC) and Arka Sasya Poshak Ras (ASPR). Together, these innovations have laid the foundation for a cost-effective, eco-friendly model of soilless farming known as cocoponics.

Arka Fermented Cocopeat (AFC) is produced by fermenting raw coir pith with selected microbial inoculants. This process, completed in about 30 days, reduces excess salts, tannins and phenolic compounds that otherwise hinder plant growth in untreated cocopeat. The end product is a substrate with improved pH, electrical conductivity, aeration and water-holding capacity. AFC has been extensively tested for various vegetables under both open and protected cultivation. In polyhouse trials, tomato grown on AFC recorded yields of 87.6 tonnes per hectare, compared to 76.7 tonnes on commercial cocopeat and 58.2 tonnes on soil (Kalaivanan and Selvakumar, 2016). Similar yield advantages were observed in cucumber, chilli, zucchini, French bean and coriander, along with better fruit quality and reduced pest incidence (Arumugam *et a*l., 2021).

Complementing AFC is Arka Sasya Poshak Ras (ASPR), a liquid nutrient formulation designed to meet the complete macro- and micronutrient requirements of vegetables grown in soilless systems (Kumari *et al.,* 2024). Unlike conventional fertilizers, ASPR is supplied in two solutions that are diluted in water and delivered through fertigation, ensuring precise and uniform nutrient availability. ASPR has been standardized for a wide range of vegetables, from fruiting crops like tomato, brinjal and cucumber to leafy greens and exotic vegetables like lettuce and parsley. Its use has resulted in faster growth, higher yields and improved shelf life of produce. By making nutrient management simple and reliable, ASPR has greatly facilitated the adoption of soilless systems by urban farmers and entrepreneurs.

Scientific Basis of Soilless Farming

The success of soilless systems lies in their ability to create an optimized root environment. In soil-based cultivation, roots are often exposed to stresses such as water logging, compaction and nutrient imbalances. In contrast, soilless substrates like AFC provide a balanced combination of water retention and aeration, ensuring that roots receive sufficient oxygen while remaining adequately hydrated. Nutrients are supplied in soluble forms, making them readily available for uptake. Since the entire root zone is under the grower's control, it is possible to maintain optimal pH and electrical conductivity, leading to more efficient nutrient absorption.

Water-use efficiency is another scientific advantage of soilless systems. Conventional soil farming loses large amounts of water through evaporation, seepage and runoff. In cocoponics and hydroponics, water and nutrients are applied directly to the root zone, minimizing losses and often allowing for recirculation. Studies at IIHR have demonstrated that soilless systems save up to 80 percent water compared to soil-based cultivation. Moreover, because substrates are free of soil-borne pests and pathogens, the use of pesticides is greatly reduced. This creates a healthier rhizosphere, fostering beneficial microbial activity and leading to higher plant vigor.

Soilless Farming and Urban Food Security

Food security in urban areas is not merely a question of availability but also of accessibility and quality. Fresh vegetables are vital sources of vitamins, minerals and antioxidants, yet they are often the first to be compromised in urban diets due to price fluctuations and supply chain disruptions (Oh and Lu, 2020). Soilless farming addresses these issues by enabling local production within cities. Terrace gardens, community farms and vertical farming units can supply neighbourhoods with fresh produce throughout the year, irrespective of seasonality. By shortening the distance between farm and fork, these systems reduce post-harvest losses and ensure greater freshness and nutritional quality.

Beyond food supply, soilless farming contributes to urban livelihoods and entrepreneurship (Fig. 2). Young people, especially in metropolitan areas, are showing growing interest in hydroponic start-ups, rooftop farms and farm-to-home delivery models. Women's groups and resident associations are also finding opportunities in community-based cocoponics. By generating income and employment within cities, these initiatives contribute to both social and economic aspects of urban food security. Furthermore, soilless farms align with consumer demand for safe, pesticide-free vegetables, thereby improving public health outcomes.

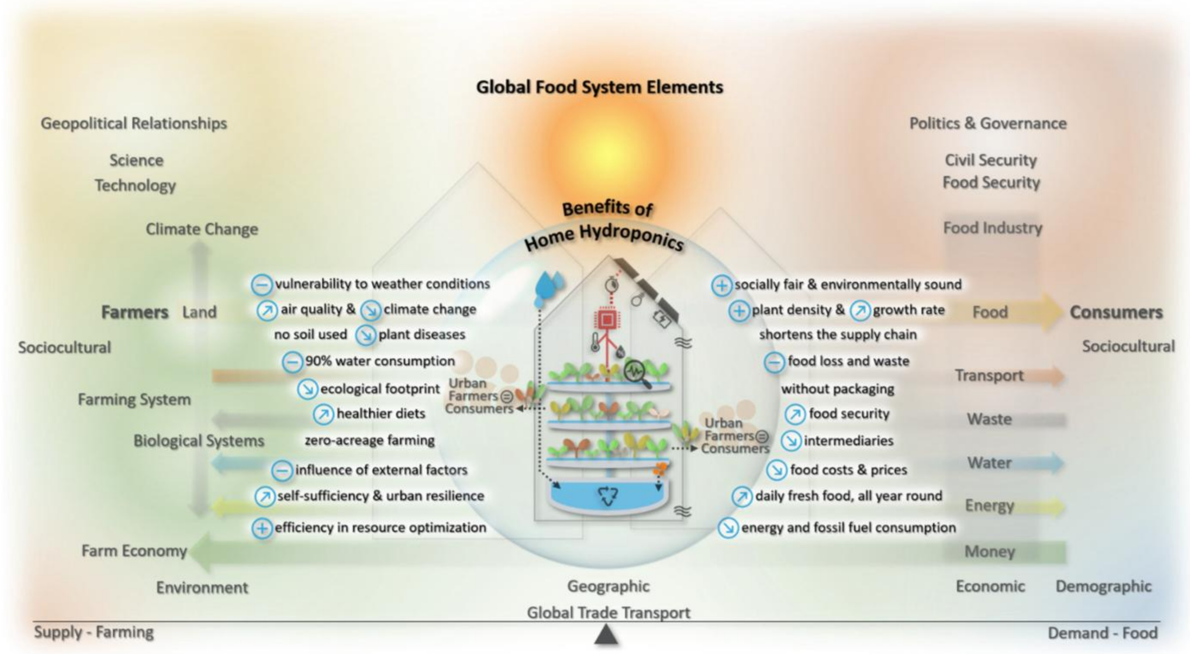


Fig. 2. Benefits Role of home hydroponics in strengthening the modern food system (Sousa *et al*., 2024).

Economic Viability

The economic feasibility of soilless farming has been well-demonstrated in IIHR trials. In a 100 square meter soilless farm, tomato yielded about 1,260 kilograms, zucchini 803 kilograms, chilli 300 kilograms, cucumber 441 kilograms and French bean 280 kilograms. The net profits ranged from Rs. 7,140 for cucumber to Rs. 35,960 for zucchini per 100 square meters. Such returns are impressive given the small space requirements and are particularly significant in the context of urban and peri-urban farming, where land is a major constraint. Moreover, with increasing consumer willingness to pay premium prices for pesticide-free vegetables, the profitability of soilless systems is likely to be even higher in urban markets (Kalaivanan, *et al.*, 2025).

Challenges and Limitations

Despite its promise, soilless farming is not without challenges. The initial investment required for protected structures, irrigation systems and substrates can be a barrier, particularly for small and marginal farmers. Technical knowledge is another limitation; growers need training in preparing nutrient solutions, monitoring pH and EC and managing environmental conditions. Although cocopeat is renewable and widely available, its quality varies and proper processing is essential to avoid crop failures. Additionally, not all crops respond equally well to soilless systems. While tomatoes, cucumbers and leafy greens thrive, some crops such as peas and cabbage perform better in soil. Policy support, subsidies and awareness campaigns are therefore critical for scaling up soilless farming in India.

Future Prospects

The future of soilless farming is deeply intertwined with technological innovations and sustainable urban planning. The integration of IoT sensors and artificial intelligence into hydroponic and cocoponic units can automate nutrient management, irrigation and climate control, making these systems more efficient and user-friendly. Linking coconut processing industries with cocoponics farms can create circular economy models where agro-waste is recycled into productive inputs. Soilless farming also holds immense potential for climate resilience, as it can operate independently of degraded soils and erratic rainfall. In drought-prone areas, urban slums and high-rise cities, rooftop and vertical farms can provide reliable sources of nutrition.

At the policy level, governments are increasingly recognizing the importance of urban agriculture. Inclusion of soilless farming in smart city missions, urban greening projects and food security programs can accelerate its adoption. Partnerships between research institutions, private sector players and community organizations will also be crucial. In the coming decades, soilless farming is likely to move beyond niche markets into mainstream urban food systems, transforming how cities grow and consume their vegetables.

Conclusion

Soilless vegetable farming represents more than just an agricultural innovation; it is a sustainable pathway for feeding the cities of the future. By decoupling vegetable production from soil and harnessing renewable substrates and precise nutrient management, soilless systems offer higher productivity, resource-use efficiency and resilience. The innovations from ICAR–IIHR, particularly Arka Fermented Cocopeat and Arka Sasya Poshak Ras, have demonstrated that soilless farming can be both affordable and scalable under Indian conditions. Integrating these technologies into smart cities can create greener, healthier and more self-reliant urban food systems. With adequate policy support, awareness and technological integration, soilless farming can transform rooftops, balconies and vertical spaces into vibrant food hubs, ensuring nutritional security for urban populations while safeguarding the environment.

References

Arumugam, T., Sandeep, G. and Maheswari, M. U. (2021). Soilless farming of vegetable crops: An overview. Pharma Innov. J, 10(1), 773-785.

Kalaivanan, D. and Selvakumar, G. (2016). Soilless cultivation of vegetables and ornamental crops. J. Agric. Rural Dev, 43, 23-26.

Kalaivanan, D., Selvakumar, G. and Rathinakumari, A. C. (2022). Soilless cultivation to secure the vegetable demand of urban and peri-urban population. In Recent Research and Advances in Soilless Culture. IntechOpen.

Kalaivanan, D., Selvakumar, G., Hebbar, S. S. and Rathinakumari, A. C (2025). Cocoponics: A Futuristic Soilless Vegetable Production System for Terrace/ Rooftop/ Polyhouse/ Vertical Garden.

Kumari, S., Sankhyan, N. K., Singh, D., Sharma, R. P. and Kumar, N. (2024). Nutrient Management in Protected Conditions including Soilless Cultivations.

Lakhiar, I. A., Yan, H., Syed, T. N., Zhang, C., Shaikh, S. A., Rakibuzzaman, M. and Vistro, R. B. (2025). Soilless Agricultural Systems: Opportunities, Challenges, and Applications for Enhancing Horticultural Resilience to Climate Change and Urbanization. *Horticulturae*, *11*(6), 568.

Oh, S. and Lu, C. (2023). Vertical farming-smart urban agriculture for enhancing resilience and sustainability in food security. The Journal of Horticultural Science and Biotechnology, 98(2), 133-140.

Sousa, R. D., Bragança, L., da Silva, M. V. and Oliveira, R. S. (2024). Challenges and solutions for sustainable food systems: The potential of home hydroponics. Sustainability, 16(2), 817.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

An insight into red belly pacu fish farming in farmponds

Tamizhkaviya, S., Velmurugan, A., Cheryl Antony, Aanand, S and Somu Sunder Lingam, R

Directorate of Sustaianble Aquaculture, Tamil Nadu Dr. J. Jayalalitha Fisheries University, Nagapattinam – 611 002

Abstract

Pacu (*Piaractus brachypomus*), an exotic fish native to the Amazon basin, has emerged as a potential species in Indian freshwater aquaculture. Its rapid growth, omnivorous feeding habits, tolerance to varied water conditions, and high market demand make it as a promising species. In India, pacu farming was initiated in 2005 and formally approved in 2024, with official guidelines released by the National Fisheries Development Board. Culture practices involve scientifically designed farm ponds, careful seed selection and stocking, efficient feeding strategies, and regular water quality management to ensure optimal growth and survival. Pacu reaches marketable size (800 g–1000 g) within 7–8 months, offering farmers a production potential of 8–10 tonnes per hectare. In addition to its economic significance, pacu is valued for its nutritional profile, being rich in protein, essential amino acids, omega-3 fatty acids, and vitamins. With increasing demand for healthy fish food, pacu farming holds promise for sustainable aquaculture diversification and enhanced farmer livelihoods in India.

Key words: Pacu; freshwater aquaculture; pond culture; seed stocking; feed management; sustainable aquaculture.

Introduction

In India, fisheries play a pivital role as an important economic activity and stand as a thriving sector enriched with diverse resources and potential. Currently, with an annual production of approximately 18.42 million metric tonnes, India ranked second in the world total fish production. Freshwater aquaculture contributes to more than 75% of this total production. Rearing of fish in freshwater ecosystems is considered as an important agricultural practice in India, playing a key role in domestic fish production. With advancements in technology and improved aquaculture methods, freshwater fish production has significantly increased in the past few years. Earlier, Indian major carps such as Catla, Rohu, and Mrigal, along with freshwater prawns, are the commonly cultured species in freshwarer bodies. States like Andhra Pradesh, Tamil Nadu, and West Bengal are the leaders in freshwater fish production. Additionally, fish farming helps to improve the income of farmers and contributes to overall economic development. In the recent times, among the various farmed food fish, pacu has emerged as an important exotic food fish in Indian aquaculture. The fast growth rate, omnivorous feeding habits, high tolerance to varied conditions, and high nutritional value make pacu as a promising species in India fish farming.

Pacu, scientifically known as *Piaractus brachypomus*, is native to the Amazon and Orinoco river basins of South America. In Tamil Nadu, it is locally known by various names such as Pamphlet, Roopchand, Red-bellied Pacu, Yeri Vaaval, or Paarai meen. It belongs to the family Characidae and it is closely related to Piranha and Silver dollar fish. Pacu is commonly found in rivers, canals, and lakes. Pacu is recognized as a major aquaculture species in several countries including Colombia, Brazil, Peru, Venezuela, Central America, Vietnam, Thailand, Malaysia, Bangladesh, and China. In China, Pacu has been cultured since 1985, and due to its rapid growth and high production, it is now widely distributed across domestic water bodies in Southern China.

In India, pacu farming has been began during the year of 2005. However, the Ministry of Fisheries officially approved its farming in 2024 and followed by this, the National Fisheries Development Board (NFDB) released guidelines for Pacu farming in India. Therefore, understanding pacu fish culture in Indian conditions is the need of the hour as the demand for pacu fish is increasingly predominantly.

Rearing of red belly pacu in farm ponds

1. Pond construction

A pond with clayey soil containing at least 40% sand is ideal for pacu culture. The soil pH should be between 6.5 to 7.0, which helps to maintain a water pH of 7.0 to 8.0. However, pacu can tolerate water pH ranging from 7.5

to 8.9. The pond depth should be at least 1.5 meters. The minimum area of farm pond for pacu culture should be 500 m^2 and it can be extended up to 2-3 acres based on the farmers land availability. Based on the topography of land, either excavated (flat areas) or embankment (low lying area) type of farm ponds can be constructed. In general, inlet and outlet pipes should be placed directly opposite to each other to ensure proper water flow. Additionally, the pond bottom should be slightly elevated near the inlet and sloped downwards towards the outlet. This design facilitates easier water discharge and fish harvesting. Even a construction of small harvesting sump or pit near the outlet of pond, further ease the harvesting activity.

If the soil of site and pond does not fulfill the requirements of water holding capacity, then lining of ponds with high density polyethylene sheet (black colour; above 400 micron thickness) is recommended to avoid seepage.

Liming of pond

Pond ready for stocking

2. Pond preparation and fertilization (pre-stocking)

In a newly constructed farm pond, if there is a pH fluctuation, then to maintain optimal pH levels, lime must be applied before stocking. Since pacu are omnivores, it is important to enhance the pond's natural productivity of both phytoplankton and zooplankton. In general, around 5000 kg/ha of dried cow dung or 10 kg of single super phosphate (SSP) should be applied at least two weeks prior to stocking. This promotes the production of live natural food organisms necessary for the fish fry. Otherwise, an organic juice (3 days fermented slurry of cow dung, rice bran, groundnut oil cake, jaggery and yeast) can be applied at the rate of 200 L/1000 m^2 pond area to ensure proper livefeed production.

In the case of existing fish culture pond, then the pond preparation methods may vary. The harvested farm ponds have to be scientifically prepared to avoid the crop failure or reduced production in the subsequent cultures. The standard pond preparation procedures, such as drying (for 20-30 days until crack formation in bottom of the pond to release the toxic gases impounded in soil) and ploughing (exposing of bottom soil to sun and air which improves soil aeration and nutrient level). Followed by this, liming and fertilization can be done. Parallely, biosecurity measures such as bird fencing (to protect the fish from fish earing predatory birds), crab/snake fencing (to avoid the entry of disease carrying crabs and fish eating snakes into the pond), water inlet screeners (to avoid the entry of weed fish) have to be installed to avoid the unwanted mortality to fish.

3. Seed selection and stocking

The selected fish seedlings should be healthy, active, and free from parasitic infections and injuries. When purchasing fish seedlings from hatcheries for rearing purposes, it is recommended to select seedlings weighing at least 10 grams to ensure better survival rates. Additionally, the selected seedlings should be uniform in size. Further, precautionary measure such as conditioning, oxygen packing, proper transportation have to ensured from hatchery to rearing sire. In general, prior to transporting the fish seedlings from the hatchery, it is essential to condition them for 6 to 12 hours (depending on the distance)

Pacu seed

in hapas or tanks. For transport, around 200 fish seedlings can be packed in a polythene bag (size: 74 cm × 46 cm, thickness: 0.0625 microns) filled with one-third water and two-thirds oxygen. It is best to transport fish seedlings during early morning or evening hours.

Before releasing the fish into the rearing pond, the sealed polythene bags should be floated in the pond water for 10 to 15 minutes. This process helps the seedlings to adjust with the pond water temperature and prevents thermal shock. After this acclimatization period, the seedlings can be gently released from the polythene bags into the pond. The recommended stocking density for monoculture of pacu is 10000 fingerling/ha (1 fish/m^2) with a stocking size of 10 g. However, many fish farmers in Tamil Nadu follow a nursery-based rearing method, where 50,000 to 100,000 fingerling per hectare are stocked in ponds. These are then sold for grow-out farming in tanks or reservoirs, resulting in good profits as second seed or advanced fingerling. In polyculture systems where pacu cultured with Indian major carps, around 15–20% of pacu fingerling were stocked in the total stocking density.

4. Feed and water quality management (post-stocking)

Pacu fish are mid-water feeders. Mostly the farm pond farmers are using farm made feed using the agricultural byproducts. They can be fed with a mixture of groundnut oil cake and rice bran. When using floating pellet feed, it should contain:25–30% protein,4–6% fat,1% vitamins and minerals. Feeding should be done twice in a day – morning and evening. Initially, feed should be given at 5% of the fish's body weight, which can be gradually reduced to 2–3% based on the growth of the fish. It is recommended to used the boiled feed ingredients for making the farm made feed which results in better digestion and faster growth. Opposite to farm feed, commercial floating feed with more than 32% crude protein is also giving very good growth. Moreover, fertilizing the pond once in every 15 days helps to maintain the natural food production in the pond. For this 0.5 tons of cow dung per hectare (as organic fertilizer), or 10 kg of urea and 15 kg of single super phosphate (SSP) per hectare (as inorganic fertilizers) were applied. This promotes steady production of both phytoplankton and zooplankton.

Note: If proper feeding is not followed, pacu fish may begin nipping the fins of other fish. To prevent this, feed must be provided at appropriate intervals without delay.

Being an aquatic creature, all fish require some optimal water quality conditions in which they thrive and grow well. However, pacu fish tolerate and grow well in wide range of water quality conditions. Under intensive culture conditions, dissolved oxygen (DO) plays a major role in controlling the growth of fish. The optimal DO level in the pond can be monitored by visiting the farm pond during early mroning times (by 5 pm). If the fish are swimming lethargic and roaming in surface of the column, then it indicates the lethal level of DO in pond water. The optimal water quality for pacu fish culture is given below;

Sl. No	Water quality parameter	Range
1.	Dissolved oxygen (mg/l)	5-7
2.	Water temperature (°C)	22-30
3.	Salinity (ppt)	0-2
4.	pH	7.5-8.5
5.	Alkalinity (mg/l)	50-300
6.	Hardness (mg/l)	50-400
7.	Ammonia (mg/l)	0.01 – 0.5
8.	Nitrite (mg/l)	0.01 – 0.25

5. Health management and sampling (post-stocking)

Pacu fish are generally hardy species and more resistant to diseases. However, during summer, if water depth reduces below 1 meter, there is a risk of epizootic ulcerative syndrome (EUS) or similar diseases. Also, during dense algal blooms, the gills of fish may get clogged, leading to mortality. To avoid this maintain the water depth above one meter. Regularly monitor algal density using a secchi disc, and manage it accordingly (optimum Secchi disc visibility depth is 15 to 30 cm.

For consistent and optimal growth, fortignt or monthly sampling is recommended I which the fish were caught using a cast net and their growth was recorded. Also, check any signs of disease or infection during sampling.

6. Harvesting

Pacu fish reach a marketable size of around 800 grams to 1 kilogram within 7 to 8 months based in feeding strategies and stocking density. Those who are targeting for yearling or advanced fingerling production can expect an average size of 100-150 g within 3-4 months of culture. The price of advanced fingerling may vary from 180 to 280 / kg based on the season in which one kg of fish consists of 5-8 pieces. On ther other side, the marketable size fish fetches an average price of 150 to 200/Kg. Overall, a farmer can expect 8 to 10 tonnes per hectare as a final production.

Harvested pacu fish

Nutritional benefits of pacu fish and conclusion

Pacu is lean fish which made up of approximately 17% protein and 1.1% fat. Additionally, the flesh of pacu contains 80% essential amino acids out of the total amino acid content. The omega-3 fatty acids present in pacu are beneficial for heart health and brain development. Vitamins such as A, B, and D are also found in pacu fish which supports bone health, immune function and metabolism in human body. The presence of Vitamin A helps to maintain eye health and may prevent age-related vision problems. Moreover, it contains a good amount of minerals which protects the immune system and cell growth in human. Therefore, in future pacu will be a major food fish in human diet and the burgeoning demand for healthy fish food can be met through species diversification based sustainable fish farming activities.

References

Singh, A. K. (2018). Apprehensions and issues related to pacu *Piaractus brachypomus* farming in India. Journal of Fish Research, 2(1).

Ananias, I.M., Silva, S.S., Souza, A.S., dos Santos, F.A.C., Magalhães, T.B., Martins, W.J.F., Favero, G.C. and Luz, R.K. (2025). "Effect of stocking density on growth and survival of pacu (Piaractus mesopotamicus) and tambaqui (*Colossoma macropomum*). Fishes, 10, 171.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

The Functional Food for Supporting Human Nutrition and Health: Oats

Ravi Raj*, Shubham* and S. N. Mishra#

*M.Sc. (Ag.) Student, Department of Genetics and Plant Breeding,
Department of Genetics and Plant Breeding, Faculty of Agriculture,
Prof. Rajendra Singh (Rajju Bhaiya) University, Naini, Prayagraj- 211010
Corresponding author: - shubhamkumar08050@gmail.com

Introduction

Oat (*Avena sativa* L.) is a widely grown cereal that is valued as a food staple and for its health benefits. Oats are different from other grains because they have a unique nutrient profile and bioactive compounds linked to various health advantages (Paudel *et al*., 2021; Alemayehu et al., 2023). One of the most important nutritional elements in oats is the soluble fiber **β-glucan**. This fiber has been focused of many research for its cholesterol-lowering and glycemic effects (Whitehead *et al*., 2014; Kendall *et al*., 2022). Besides β-glucan, oats have special antioxidants, such as avenanthramides, and various phytochemicals that contribute to their status as a functional food (Paudel *et al*., 2021; Leszczyńska *et al*., 2023). This overview presents the main nutritional components of oats and their bioactive compounds. It also reviews the evidence for their health effects and medicinal uses.

Nutritional Composition

Oats have an unusually rich macronutrient profile compared to other cereals. They are high in complex carbohydrates (mostly starch) but also contain more protein (≈13-17%) and fat (≈6-10%) than wheat or rice. Approximately 60% of dry oat kernel weight is starch, with amylose and amylopectin comprising the vast majority of oat carbohydrate. Oats also supply a large amount of dietary fiber (around 10-15% of dry weight), with a mix of soluble and insoluble forms. In whole oats, about 40% of the fiber is soluble (largely β-glucan) and 60% is insoluble (mainly cellulose and hemicellulose). Their fat is predominantly unsaturated one of the highest fat contents among cereals, which helps to improve the fatty acid profile and may contribute to cardiovascular benefits.

In addition to macronutrients, oats are rich in micronutrients. They provide B-vitamins such as riboflavin (B_2), niacin (B_3), and pantothenic acid (B_5), And among the cereal grains that contain a high level of vitamin E.

Oats are also a good source of essential minerals that contain iron, zinc, magnesium, phosphorus and other trace elements that support metabolic and enzymatic functions (Alemayehu *et al*., 2023). Overall, oat grain contains roughly 12-17% protein, 6-10% fat, 10-15% total dietary fiber and the balance as carbohydrates.

Bioactive Compounds

In addition to essential nutrients, oats provide unique bioactive compounds linked to health benefits. The most significant is β-glucan, a soluble fiber with mixed (1→3), (1→4)-β-D-glucose linkages. β-Glucan occurs at about 2-6% of oat grain (depending on variety and processing). Because of its soluble and viscous nature in the gut, oat β-glucan produces several health benefits. Studies consistently show that it lowers serum LDL ("bad") cholesterol and helps to control a rapid and significant increase in blood glucose level after meals. Recognizing this, regulatory bodies now approve the health claim that consuming at least 3 g of oat β-glucan daily can reduce cholesterol levels and lower the risk of cardiovascular disease (Whitehead et al., 2014).

Oats are a great source of antioxidants, especially a unique group called avenanthramides—found only in oats. These compounds are powerful defenders against inflammation and oxidative damage, helping protect cholesterol from turning harmful. Amazingly, they are 10–30 times more effective than the typical antioxidants found in most other grains. Along with other natural compounds like ferulic and caffeic acids, avenanthramides make oats especially good for heart and vascular health.

Oats are also a source of plant sterols (primarily β-sitosterol, campesterol and stigmasterol) which can modestly lower cholesterol absorption, and lignans, Lignans are a class of polyphenols, which are a type of plant-based chemical compound, known for their antioxidant and potential health-promoting properties (such as secoisolariciresinol) that have been linked to antioxidant and anticancer effects. The grain's tocopherols and tocotrienols (vitamin E forms) provide additional antioxidant protection for cells. Other bioactives in oats include saponins (avenacosides) and avenanthramide derivatives that appear to modulate immunity and metabolism. In summary, oats combine fiber, vitamins, and unique phytochemicals (β-glucan, avenanthramides, sterols, tocols, etc.) into a nutrient-dense cereal with multifaceted health-promoting potential.

Health Benefits

Eating oats regularly has been linked to many health benefits, with the strongest evidence for their role in improving cholesterol levels. Studies have shown that consuming at least 3 grams of oat β-glucan per day about the amount in a single bowl of oatmeal can lower both LDL ("bad") cholesterol and total cholesterol by around 5-10%. For instance, one large review of 28 studies found that this daily amount reduced LDL cholesterol by about 6% and total cholesterol by about 0.30 mmol/L. These improvements are significant for heart health and form the basis for the official health claims on oats approved by the FDA (Food and Drug Administration, U.S) and EFSA (European Food Safety Authority).

Blood Sugar Control

Oats also help in blood sugar control. The β-glucan in oats slows down the absorption of glucose, which can improve how the body responds to insulin an especially important benefit for people with type 2 diabetes. A recent review of studies in diabetic patients found that taking about 3-5 grams of oat β-glucan daily led to meaningful improvements in blood sugar. In fact, around 3.25 grams per day for 4-8 weeks lowered long-term blood sugar levels (HbA1c) by about 0.5% and reduced fasting glucose by about 0.75 mmol/L compared to regular diets. These results highlight oats as a low-glycemic food that supports better metabolic health and diabetes management (Kendall *et al.*, 2022).

Heart Health

Beyond supporting heart and blood sugar health, oats also play a role in weight management and gut health. Their soluble fiber is fermented in the colon, producing short-chain fatty acids that help increase feelings of fullness (satiety) and support a healthy balance of gut bacteria. Some studies even show that eating oats can boost beneficial microbes in the gut while reducing inflammation (Paudel et al., 2021).

Digestive Health

The high fiber content of oats also aids digestion, promotes regular bowel movements, and has been linked to a lower risk of colorectal cancer. Observational studies suggest that people who regularly eat oats are less likely to develop obesity and metabolic syndrome (Alemayehu et al., 2023).Oats are also rich in antioxidants, especially avenanthramides, which have anti-inflammatory and protective effects. These compounds help prevent LDL cholesterol from oxidative damage and have even shown anticancer activity in laboratory and animal studies (Paudel et al., 2021; Leszczyńska et al., 2023).

Skin Health

It is not only healthy to eat it is also used in skin care. Finely ground oats, known as colloidal oatmeal, have long been used as a natural remedy for skin problems. Because of their soothing, anti-inflammatory, and anti-itch effects, they are widely included in creams, lotions, and bath products. Research shows that colloidal oatmeal can calm conditions like eczema and atopic dermatitis, reducing redness, dryness, and itching. These benefits come largely from avenanthramides, special compounds in oats that block the release of histamine and inflammatory signals in the skin. Clinical studies confirm that oatmeal-based products help improve eczema symptoms in both children and adults. Because they are both effective and safe, colloidal oatmeal preparations are officially recognized by the FDA as a skin protectant.

Neurological Health

Many research suggests that oats may even support the neuropsychological health. Traditionally, the green parts of the oat plant (called 'green oat') were used to ease anxiety and improve sleep. Today, modern trials are exploring these effects. Several studies found that a green oat extract taken for 8 weeks improved stress, sleep quality, and overall wellbeing during smoking cessation. Scientists believe this may be due to compounds in oats that influence brain chemicals related to mood. While more studies are needed, early evidence suggests oats could play a role in mental wellbeing and cognitive health.

Inspection of oats crops on field (PRSU, Prayagraj)

Challenges in Oat Utilization and Research

Despite the well-documented health benefits of oats, their utilization faces several challenges. In countries such as India, consumer awareness regarding the nutritional and therapeutic value of oats remains limited when compared to staple cereals like wheat and rice. Moreover, the high lipid content of oats makes them prone to rancidity, thereby reducing their storage stability and processing potential. Production challenges also arise, as oats are less tolerant to heat and drought stress, which restricts large-scale cultivation under changing climatic conditions. Additionally, the reliance on imported processed oats increases the cost of consumption, further limiting accessibility in developing regions. Consumer acceptability poses another obstacle, since incorporating oats into traditional dietary patterns is difficult. Finally, the scope of value-added oat-based products remains narrow, with relatively limited innovation in functional foods and nutraceuticals.

Future Prospects of Oats

The future of oats in human nutrition lies in both genetic improvement and product diversification. Breeding programs targeting biofortification could develop oat cultivars enriched with β-glucan, iron, zinc, and antioxidant compounds. Furthermore, the development of functional foods, including oat-based breakfast cereals, biscuits, noodles, and nutraceuticals, has the potential to expand consumer acceptance. Integrating oats into traditional dietary staples such as chapati, idli, dosa, and khichdi, through innovative processing may significantly enhance their cultural adaptability in regions like South Asia. Climate-resilient oat varieties that are heat- and drought-tolerant will also be critical for sustainable cultivation under global warming scenarios. Public health campaigns can further highlight the role of oats in managing diabetes, obesity, and cardiovascular diseases, thereby strengthening demand. Expansion of domestic oat cultivation, combined with supportive agricultural policies and market incentives, could reduce dependency on imports and promote oats as a sustainable health-promoting cereal crop.

Reference

Alemayehu, G. F., Forsido, S. F., Tola, Y. B., & Amare, E. (2023). Nutritional and phytochemical composition and associated health benefits of oat (*Avena sativa*) grains and oat-based fermented food products. *The Scientific World Journal, 2023,* 2730175.

Jenkins, D. J. A., Kendall, C. W. C., Sieve piper, J. L., Pauly, D., Josse, A. R., Salvatore, S., … & Vuksan, V. (2022). Effect of oats and oat β-glucan on glycemic control in diabetes: A systematic review and meta-analysis of randomized controlled trials. *BMJ Open Diabetes Research & Care, 10*(5), e002784.

Leszczyńska, D., Wirkijowska, A., Gasiński, A., Średnicka-Tober, D., Trafiałek, J., & Kazimierczak, R. (2023). Oat and oat processed products—Technology, composition, nutritional value, and health. *Applied Sciences, 13*(20), 11267.

Paudel, D., Dhungana, B., Caffe, M., & Krishnan, P. (2021). A review of health-beneficial properties of oats. *Foods, 10*(11), 2591.

Whitehead, A., Beck, E. J., Tosh, S. M., & Wolever, T. M. S. (2014). Cholesterol-lowering effects of oat β-glucan: A meta-analysis of randomized controlled trials. *American Journal of Clinical Nutrition, 100*(6), 1413–1421.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Advances in Bio-Based Food Packaging: Materials, Functions, and Smart Innovations

Robin Kaura[1], Nishant Verma[1], Gurdeep Singh[1], Amandeep Singh[2*]

[1]Dairy Engineering Division, ICAR- National Dairy Research Institute, Karnal, Haryana-132001
[2]Dairy Technology Division, ICAR- National Dairy Research Institute, Karnal, Haryana-132001
*Corresponding Author: amandeepsingh2363@gmail.com

Abstract

The growing demand for sustainable food packaging has driven the replacement of petroleum-derived plastics with eco-friendly, bio-based alternatives. These materials are derived from renewable resources, including polysaccharides, proteins, lipids, and microbial polyesters, and offer biodegradability, compostability, and a reduced ecological footprint. Although natural biopolymers often show lower moisture resistance and mechanical strength, their performance can be improved through blending, crosslinking, and incorporation of reinforcing agents. Beyond serving as passive barriers, active packaging systems have been developed to interact with food environments by incorporating antimicrobial agents, antioxidants, and gas scavengers that extend shelf life and ensure product safety. Intelligent packaging further advances this field by integrating biosensors, pH indicators, and wireless communication elements that allow real-time monitoring of food quality and freshness. Recent developments inspired by natural structures have introduced self-cleaning and self-healing surfaces, while nanotechnology has enabled improved mechanical stability, barrier properties, and antimicrobial activity. Despite these advances, challenges related to high production cost, regulatory frameworks, and industrial scalability continue to limit widespread adoption. Future progress depends on hybrid material design, bio-nanocomposites, and integration with digital technologies to achieve sustainable packaging systems that align with circular economy principles.

Keywords: Active packaging, Biobased materials, Intelligent packaging, Nanotechnology

1. Introduction

The shift toward environmentally conscious practices has driven major transformations in the food packaging sector, largely due to the ecological burden of petroleum-derived plastics. Conventional plastics, though valued for versatility, strength, and low cost, pose persistent challenges, such as non-degradability, microplastic accumulation, , and health risks from chemical leachates. This has accelerated the search for sustainable alternatives, with bio-based packaging materials emerging as promising substitutes. Derived from renewable feedstocks such as polysaccharides, proteins, lipids, and microbial polyesters, these materials offer biodegradability, compostability, and food safety advantages. Their tunable structures and compatibility with functional additives further support innovation, though limitations like lower moisture resistance and mechanical strength compared to existing plastics. Ongoing advances in blending, crosslinking, and reinforcement are steadily improving their performance.

Packaging evolution has also incorporated active and intelligent features. Active packaging interacts with food environments to slow oxidation, inhibit microbial growth, and regulate moisture through agents such as antimicrobials, antioxidants, or gas scavengers. Intelligent packaging, employing biosensors, colorimetric indicators, and electronic tags, enables real-time monitoring of product freshness, integrity, and traceability while engaging consumers. Together, these systems expand packaging functions from passive containment to responsive food safety tools. This article highlights recent progress in bio-based food packaging, focusing on: (i) classification and performance of renewable materials; (ii) enhancement with bioactive compounds to prolong shelf life; and (iii) integration of smart sensing technologies. It further examines bio-based and nanotechnology-based interventions shaping the future of sustainable intelligent packaging.

2. Bio-Based Materials for Food Packaging

2.1. Classification and Sources of Bio-Based Polymers

Bio-based food packaging systems are primarily developed from renewable macromolecules, including plant polysaccharides (starch, cellulose, pectin), proteins (zein, gelatin, soy protein), microbial polyesters (PLA, PHAs), and lipid-based structures.Polymer choice depends on availability, cost, functionality, and environmental impact. Polysaccharides, rich in hydroxyl groups, are valued for film-forming ability, safety, and biodegradability. Starch from maize, cassava, or potatoes is inexpensive and can be easily processed but water-sensitive and brittle, often requiring plasticizers or blends. Cellulose derivatives (carboxymethyl, methyl cellulose) provide mechanical strength and gas barrier properties but usually need chemical modification or solvent casting for compatibility with hydrophobic additives. In addition to polysaccharides, proteins such as soy isolate, gelatin, whey protein, and zein form cohesive, biodegradable, and edible films due to strong intermolecular interactions, though their humidity sensitivity and allergenicity can restrict their use without modification.

Microbial and synthetic bio-polyesters such as PLA (polylactic acid) and PHA (polyhydroxyalkanoate) offer properties like thermoplasticity, resilience, and are suitable for processing methods like extrusion. PLA, made by fermenting sugar to produce lactic acid, has good transparency and is easy to process, but requires industrial composting facilities for breakdown. PHAs are completely biodegradable, and their properties can be adjusted, but their high production cost limits widespread use. New sources, like algae, crop residues, and leftovers from food processing, can be used to make these polymers, promoting recycling of waste and principles of a circular economy.

2.2. Functional and Physicochemical Attributes

The efficacy of bio-based materials in food packaging applications is contingent upon their intrinsic physicochemical characteristics namely, their mechanical strength, gas and vapor permeability, thermal stability, and optical properties. An ideal bio-based packaging film should serve as an effective barrier to oxygen, carbon dioxide, and water vapor to retard spoilage and oxidation, while also maintaining structural integrity during processing, storage, and distribution.

Polysaccharide-based films generally offer low permeability to oxygen due to their dense hydrogen-bonded network but exhibit high water vapor transmission rates, which may be advantageous or detrimental depending on the food product. Proteinaceous films provide intermediate moisture barriers and exceptional transparency, making them suitable for visible monitoring systems. In contrast, PLA and PHA exhibit relatively balanced barrier and mechanical profiles, rendering them compatible with conventional packaging lines and commercial usage. To overcome the limitations inherent to single-component systems, researchers often employ polymer blending, nanofiller incorporation, and crosslinking strategies to tailor and enhance the material's functional properties. The use of plasticizers (e.g., glycerol, sorbitol) is also commonplace to mitigate brittleness and improve flexibility.

3. Functional Enhancements: Active Packaging Technologies

The conventional role of food packaging as a passive barrier to external environmental factors is increasingly being reconceptualized in light of contemporary advancements in material science. In this regard, active packaging systems characterized by their capacity to interact dynamically with the food product and its surrounding environment represent a transformative innovation in the domain of bio-based packaging. By incorporating functional agents capable of modulating chemical, microbial, or physicochemical processes, active packaging can substantially augment the shelf life, quality, and safety of food products.

3.1. Concept and Functional Agents

Active packaging relies on integrating substances that either scavenge harmful compounds (oxygen, ethylene, moisture) or release beneficial agents (antioxidants, antimicrobials, CO_2). In bio-based systems, these functions are achieved by embedding natural compounds such as essential oils, phenolic acids, plant extracts, or metal nanoparticles into biopolymer matrices. Antimicrobial agents remain central to such systems. Natural compounds like thymol, eugenol, cinnamaldehyde, and carvacrol, along with oils from cinnamon, oregano, or thyme, exhibit broad-spectrum activity. Their incorporation into polymers such as chitosan, zein, or starch yields films that suppress microbial growth via membrane disruption, oxidative stress, or metabolic inhibition. Inorganic agents like silver nanoparticles, zinc oxide, and titanium dioxide also provide potent antimicrobial effects, though regulatory and toxicity concerns persist.

Antioxidant-based packaging delays lipid and pigment oxidation in oxygen-sensitive foods. Compounds such as curcumin, tannic acid, and tocopherols are commonly embedded in biodegradable films to scavenge free radicals and chelate metals, proving effective for meat, dairy, and bakery applications where rancidity is problematic. Gas-modifying elements further enhance performance: oxygen scavengers (iron powder, ascorbic acid) and CO_2 emitters (sodium bicarbonate–citric acid) adjust package atmosphere, while ethylene absorbers employing potassium permanganate or activated carbon slow ripening in climacteric fruits. Collectively, these strategies extend shelf life and maintain product quality.

3.2. Controlled Release and Matrix Compatibility

A critical consideration in the design of bio-based active packaging is the controlled and sustained release of active compounds. The diffusion kinetics are largely governed by the interaction between the biopolymer matrix and the functional molecule, the degree of crosslinking, and the environmental conditions (e.g., temperature, humidity). Polysaccharide matrices, being hydrophilic and porous, often facilitate faster diffusion, whereas protein-based or polyester matrices may offer more prolonged release profiles. To optimize performance, multi-functional systems are being developed by co-encapsulating different active agents, employing emulsions or nanocarriers, and engineering micro/nano-structured matrices. These strategies ensure the targeted and responsive delivery of bioactives, thereby enhancing their efficacy without compromising the integrity of the packaging film.

4. Intelligent Packaging Innovations

In parallel with the advancement of active packaging systems, a complementary and equally transformative trend in sustainable packaging science is the emergence of intelligent packaging technologies. These systems transcend the conventional protective function of packaging by enabling real-time monitoring, communication, and indication of the internal and external status of food products throughout their storage and distribution cycles. Within the paradigm of bio-based packaging, the integration of intelligent functionalities is particularly compelling, as it harmonizes environmental sustainability with advanced food quality assurance.

4.1. Concept and Functional Categories

Intelligent or "smart" packaging is characterized by its ability to detect, sense, and communicate information on food quality, freshness, spoilage, or environmental exposure. This is achieved through embedded indicators or sensors (as summarized in Table 1) that respond to physicochemical changes such as pH, temperature, gas emissions, or microbial metabolites. In bio-based packaging, the most common intelligent tools are colorimetric indicators, which show visible color changes triggered by biochemical shifts. pH-sensitive pigments like anthocyanins, betalains, and curcumin have gained particular interest; when incorporated into biopolymer films (cellulose, chitosan, PLA), these pigments undergo structural changes with pH variations, providing a simple and effective means of spoilage detection in perishables such as meat and fish.

Gas-sensitive indicators targeting ammonia, hydrogen sulfide, or carbon dioxide also play a key role in microbial spoilage monitoring. For example, starch-based films with red cabbage anthocyanins exhibit quantifiable color changes in response to volatile amine buildup during seafood degradation. Importantly, such systems are biodegradable, edible, and non-toxic, making them well suited for direct food-contact applications while advancing sustainable packaging goals

Table 1: Examples of active and intelligent bio-based packaging systems

Type	Functional Additive	Base Polymer	Functionality	Target Product
Antimicrobial	Oregano essential oil	Chitosan	Inhibits bacteria (e.g., *E. coli*, *S. aureus*)	Fresh produce, poultry
Antioxidant	Curcumin	Gelatin	Prevents lipid oxidation	Meat, bakery products
Moisture control	Glycerol + clay nanoparticles	Starch	Moisture scavenging, improves flexibility	Snacks, cereals
Oxygen scavenger	Iron oxide	PLA	Reduces O_2 levels inside package	Packaged meat, cheese
pH Indicator	Red cabbage anthocyanin	Starch-cellulose blend	Color change with spoilage (alkaline gases)	Fish, seafood, pork
Gas Indicator	Bromothymol blue	Chitosan-PVA composite	Monitors CO_2/volatile amines	Fermented foods, meat
RFID-based smart tag	NFC passive chip	PLA/cardboard hybrid	Transmits freshness or temperature data	Cold-chain logistics (milk, seafood)

4.2. Advanced Sensor Integration and Communication Technologies

Beyond visual indicators, more sophisticated systems are under development that couple bio-based substrates with electronic components, including biosensors, RFID tags, and data carriers. Chitosan and gelatin hydrogels, for example, have been engineered as matrices for chipless RFID systems that can sense pH and humidity changes via alterations in electrical resonance frequencies. Additionally, integration of enzymatic biosensors into biodegradable films enables detection of specific pathogens or enzymatic activity associated with spoilage. The convergence of printed electronics and biodegradable substrates has opened new avenues for the development of fully compostable intelligent packaging systems. These include temperature time integrators (TTIs) that track cumulative thermal exposure, fluorescent bio-markers that respond to microbial activity, and even NFC-enabled labels that allow consumers to assess product freshness using smartphones.

5. Bio-Inspired Approaches and Nano-Enabled Enhancements in Bio-Based Packaging

Bio-inspiration refers to emulating structural and functional features of natural systems to improve material performance. In food packaging, the lotus leaf effect is a prominent example, where hierarchical surface microstructures impart superhydrophobic and self-cleaning properties. Replicating these on biopolymers through micro-embossing, templating, or laser etching reduces water affinity, microbial adhesion, and contamination. Another key strategy is self-healing, inspired by biological tissues. By incorporating reversible covalent or supramolecular bonds into bio-based films, materials can autonomously repair microcracks or damage during handling. Proteins and polysaccharides, owing to diverse functional groups, are particularly suitable for such chemistries, enhancing durability and reusability.

Nanotechnology further elevates bio-based packaging performance. Incorporating nanofillers such as cellulose nanofibers, graphene oxide, montmorillonite clay, silver nanoparticles, or zinc oxide markedly improves mechanical strength, thermal stability, and barrier resistance to gases and moisture. Nanofillers increase diffusion tortuosity, thereby reducing oxygen and vapor permeation. Additionally, several nanomaterials exhibit antimicrobial or UV-shielding properties, adding value in active packaging. For example, ZnO-incorporated starch films extend shelf life of perishables while maintaining photostability and transparency under storage. Together, bio-inspiration and nanotechnology represent complementary approaches for developing sustainable, multifunctional, and high-performance biodegradable packaging systems.

6. Challenges and Future Directions

Despite advances in bio-based food packaging with active and intelligent functionalities, several challenges hinder large-scale commercialization. Biopolymers often display hydrophilicity, reducing moisture resistance, dimensional stability, and barrier properties in humid conditions. Their limited mechanical and thermal stability restrict application in high-speed industrial processing. Performance-enhancing strategies such as blending, crosslinking, and nanofiller incorporation improve properties but complicate recyclability and regulatory approval. Controlled release of active agents also remains problematic, as many bioactives are volatile or thermally unstable, making consistent delivery difficult without premature depletion or food interactions. Intelligent indicators face issues like fading signals, color instability, and short shelf life under variable storage. Economic and regulatory barriers further constrain adoption; biopolymers remain costlier than petrochemical plastics, with limited supply chains and lack of standardized processes reducing competitiveness. Integrating digital technologies such as IoT and blockchain may support traceability, while circular economy strategies will be essential for sustainable scaling.

7. Conclusion

The transition toward sustainable, functional, and intelligent packaging systems represents a critical frontier in addressing the intertwined challenges of environmental degradation, food waste, and consumer safety. Bio-based packaging materials, derived from renewable and biodegradable sources, have demonstrated significant promise as eco-compatible alternatives to petroleum-based plastics. Their inherent versatility allows for structural modifications and integration with active agents that mitigate microbial spoilage and oxidative deterioration, as well as intelligent elements capable of real-time monitoring and consumer interaction. The convergence of biopolymer science, nanotechnology, and bio-inspired design principles has catalyzed the emergence of multifunctional systems with enhanced performance and responsiveness. Nonetheless, realizing their full industrial and societal impact necessitates overcoming persistent hurdles related to material limitations, regulatory compliance, cost-efficiency, and scalability. Going forward, interdisciplinary collaboration and systems-level thinking will be pivotal in driving the development of next-generation bio-based packaging that is not only sustainable and safe but also dynamically aligned with the evolving demands of a digitized and circular food economy.

References

Abdullahi, A., Korumilli, T., & Rao, K. J. (2025). Revolutionizing Food Packaging with Biobased Polymers, Active and Intelligent Materials for Enhanced Food Safety and Sustainability: Review. *Food and Bioprocess Technology*. https://doi.org/10.1007/s11947-025-03868-9

Huang, K., & Wang, Y. (2025). Advances in Bio-Based smart food packaging for enhanced food safety. *Trends in Food Science & Technology*, 104960. https://doi.org/10.1016/j.tifs.2025.104960

Sahota, S., Soman, V., Thakur, D., & Poddar, M. K. (2025). Biobased plastics and their nanocomposites: emerging trends in active and intelligent food packaging applications. *Journal of Food Science and Technology*, *62*(9), 1618–1633. https://doi.org/10.1007/s13197-025-06359-z

Sharma, S., Sharma, S., & Vats, T. (2024). Bio-based food packaging a sustainable alternative: availability, viability and legislation. *Polymer Bulletin*, *82*(4), 1017–1056. https://doi.org/10.1007/s00289-024-05554-w

Zhong, J., McClements, D. J., He, K., Zhang, Z., Zhang, R., Qiu, C., Long, J., Zhou, X., Zhao, J., Jin, Z., & Chen, L. (2025). Innovative applications of bio-inspired technology in bio-based food packaging. *Critical Reviews in Food Science and Nutrition*, 1–14. https://doi.org/10.1080/10408398.2025.2450524

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Importance of Organic Vegetable Cultivation

Jyothi R, Raghavendra Yaligar, Kavitha Ullikashi, Radha J, Revathi R M, Narappa G

ICAR-Krishi Vigyan Kendra, Koppal

Vegetables are the broad group of plants that can be eaten. The parts that canbe eaten could be whole plant, leaves, stalks, seeds, flower buds etc. Vegetables are low in calories but high in nutrients such as vitamins, minerals and fibres. They also contained natural chemical compounds i.e. antioxidants that can help cells from oxidative damage. As vegetables are the good source of dietary fibres, eating more of vegetables keep easy bowl movement and prevent constipation. The vegetables which are rich in potassium are helpful in reducing blood pressure by helping kidneys to filter sodium out of the body. Vegetables rich in Vitamin K prevents building up of calcium in arteries and lower the risk of artery damage. Non starchy vegetables with low glycaemic index effective for blood sugar management. Phenols which are natural chemical present in the vegetables helpful in body inflammation reduction and lower the oxidative damage to the body cells. Further vegetable cultivation are the good source of better income and employment opportunities and nutritional benefits for small holder farmers, rural labours and consumers.

Vegetables with larger amount of beneficial nature are cultivating in a 204.96 million hectares with 212.91 million tonnes of production. In India majority yield loss of these vegetables are significantly due to pest and diseases. Common pests include Aphids, white flies, caterpillars, thrips and beetles and diseases like bacterial leaf spot, club rot, early blight and powdery mildew are frequently encountered ones. It was estimated that there is 27.7 % loss in vegetable production globally, out of which 8.7% is through insect and pests. In India the estimated vegetable crop loss during production level could be up to 25-30% out of which 10-35% of annual loss was observed because of pest and diseases. Loss due to pests and diseases not only affect the quantity but also quality of the vegetable crop producer. Damage level of all the insect and pests are not same, some insect like fruit and shoot borer (*Leucinodes orbonolies*) in brinjal can damage up to 75% and Dimond back moth (*Plutella xylostella*) in cabbage can damage up to 52 %.

India is one among the largest consumer of pesticides in the world. However, per hectare consumption of pesticides is mush lower i.e. 05 kg/ha. Pesticide consumption in other countries like Saint Lucia 20 kg/ha, Maldives 17 kg/ha and China 13 kg/ha. Indian Overall consumption of pesticides is sustainable due to its larger agriculture land area. In India 74.66 % of farmers apply pesticide at every 10 days interval and 19.33 % farmers apply as and when it is necessary. The top ten states of India which are consumers of larger quantity of pesticides are Maharashtra, Uttar Pradesh, Punjab, Telangana, Haryana, West Bengal, Jammu and Kashmir, Rajasthan, Karnataka and Tamil Nadu. The Major type of insecticides used in vegetables are organophosphorus, pyrethroids, carbamate, organochlorine, nereistoxin analogue group, and neonicotinoids and others. Neonicotinoids include imidacloprid, acetamiprid and thiamethoxam which is commonly used for sucking pests. Pyrethroids such as bifenthrin, cyfluthrin and permethrin. And some other insecticides like indoxacarb, chlorantraniliprole and fipronil each of these target specific pests. Pesticide ranking according to their usage like fungicide > herbicide > ovicide > insecticide > acaricide > nematicide > miticides. As mentioned by the World Health Organization nearly 10.00 lakh people suffer from acute poisoning of pesticide annually. The concern thing is incorrect use and selection of pesticide for particular pest and diseases to a crop grown.

Nearly one-third of the agricultural products are produced by using pesticides. In India more than 241 pesticides and 41 combination products are registered for use in agriculture. Out of these > 62 insecticides and > 40 fungicides and 7 plant growth promoters has been registered only for vegetable crops. 13-14 % pesticides used in the country are applied for vegetable crops only. Despite of advantages of pesticides over controlling the pest and diseases, they poses significant hazard to human health and environment. The pesticide element enters our atmosphere and contaminates water, food and soil. Toxicity of pesticide occurs when it inhaled, ingested or come in contact with skin and eye. If this happens repeatedly it leads to chronic toxicity. Neurotoxicity, mutagenicity, carcinogenicity, teratogenicity and endocrine disruption are the different types toxicity produced by the prolonged pesticide exposure. Through in-vivo and in-vitro studies it was observed that, chronic exposure to pesticides can lead to an increase in cancer, neurological disorders, and Parkinson's disease. Oxidative stress, damage to DNA, activation of cytokine cascade, apoptosis, and various types of tissue disorders observed in liver, kidney, lung, and brain tissue.

For effective management of pest and diseases of vegetable, integrated approaches like utilization of cultural practices, biological control, use of organic inputs, crop rotation, use of crop residue, animal manure, growing of legume and green manure crops helps in the better quality of the vegetable produce. Further if found necessary judicious use of agrochemicals at recommended dosage could be done. Organic vegetable cultivation helpful for protection of environment and healthy food production. At present sustainable organic vegetable cultivation ensures to fetch premium price in domestic and international market. The estimated growth of organic farming is nearly at the rate of 30 % a year world wide in response to market demand. Larger portion of the grower now shifting to organic practices to meet the demand. Organically grown vegetables contains lesser level of nitrates and higher level of vit C, total sugar, minerals like phosphorous, magnesium, phenolic compounds, peroxidase which are helpful for healthy body activities.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Mobile Applications in Agriculture and Allied Sectors

Dr. P. Nagarjuna Reddy[1], Dr. D. Sreedhar[2] and Dr. B. Govinda Rajulu[3]

[1]Scientist (Agril. Extenison), KVK, Periyavaram, Tirupati Dist.
[2]Senior Scientist and Head, KVK, Periyavaram, Tirupati Dist.
[3]Director of Extension, Dr. YSRHU, West Godavari Dist. Andhra Pradesh

In recent years, the agriculture in India has witnessed a significant transformation driven by the integration of modern technologies particularly in usage of mobiles in agriculture. One of the most notable advancements has been the proliferation of mobile applications designed to cater to the unique needs and challenges of farmers. Mobile applications, or apps, have emerged as powerful tools that bridge information gaps, empower decision-making, and enhance overall agricultural productivity (Singh, N. K. et al. 2023).

Mobile applications help in providing up-to-date information services to the farmers such as package of practices, market information, weather forecasting, the input supply, and credit availability. Farmers get timely and accurate information about the latest technologies and market information and get contact with the experts for any query about agriculture.

Mobile applications provide agricultural advisories through text and video messaging services. They are used to access information on real-time weather data like temperature, rainfall, sunshine hours, etc., which directly affect agricultural decision-making. Online crops/livestock/ poultry/fisheries etc are possible through mobile apps.

Mobile apps can be utilized for delivering services offered by the Government to farmers in the form of inputs and subsidy distribution. It can be used in the management of irrigation systems in large fields, sensor-based farming, identification of different soil types, etc. It facilitates effective farm management by recording data, analyzing it, and giving suitable recommendations for different enterprises. It helps in better marketing and storage of agricultural produce.

Popular Agriculture Mobile Applications used by Farmers in India

1. **Kisan Suvidha:** For the event and empowerment of the farmers and villages of rural areas it was launched by Honourable Prime Minister Narendra Modi in 2016. The application design is efficient and provides a user-friendly interface. Kisan Suvida was developed by the Ministry of Agriculture and Farmers Welfare for farmers in facilitating the dissemination of data on Market Prices, Agro-advisory, Weather, Extreme Weather Alerts, Plant Protection, Dealers – Fertilizer, Seed, Farm Machinery, Pesticide, animal husbandry, crop insurance, Call to Kisan Call. Farmers get to learn and practice several new technologies provided in application. Problems regarding agriculture can be solved with direct communication of farmers and scientists in the platform provided by the application. The knowledge is currently provided in English, Hindi, Odia, Tamil, Gujarati, Marathi, Punjabi, Telugu and Bengali. In a study it had been reported that 28% of the farmers had the opinion that this application was very effective, while of 54% farmers had the opinion that this application had a medium level of effectiveness (Agashe et al. 2019).
2. **IFFCO Kisan Agriculture App:** This application was launched in 2015 by IFFCO Kisan, a subsidiary of Indian Farmers' Fertilizer Cooperative Ltd. It aspires to assist Indian farmers to make knowledgeable decisions with the help of modified information associated with their needs. The farmers can access a range of instructive modules which include weather, agricultural advisory, agriculture information library within the style of the text, market prices, audio, videos and images with the selected language of farmers. The application also provides helpline numbers to induce connection with Kisan centre Services. The application supports eleven languages across India viz. English, Hindi, Odia, Telugu, Bengali, Tamil, Punjabi, Malayalam, Marathi, Kanad and Gujrati.
3. **RML Farmer:** Krishi Mitr RML Farmer may be one kind of agriculture application where farmers can carry on with the newest product and market prices, accurate usage of fertilizers and pesticides, weather outlook

and advisory, farm and farmer related news. It also provides agricultural guidance and news concerning the government's agricultural policies and schemes. Farmers can make a selection from larger than 450 crop varieties, 1300 mandis, and 3500 weather conditions regions across 50,000 villages and 17 states of India. It functions with the assistance of explicit tools planned to inspect or provide information on several aspects of farming practice. Eg. CropDoc assists the farmers in identifying situations that affect their crops at the appropriate time and recommends relevant actions; Farm Nutri suggests common and specific nutrient recommendations, which are offered inside the kind of a suggested fertilizer dose.

4. **Pusa Krishi:** This application was launched by the Union Agriculture Minister in 2016. It aims to assist farmers to get information regarding technologies developed by the Indian Agriculture Research Institute (IARI), assisting the farmers to receive increased returns. The application helps farmers by providing them information associated to novel kinds of crops developed by Indian Council of Agriculture Research (ICAR), sustainable farming cultivation practices also because farm machinery and implements help in elevating the income of farmers.
5. **AgriApp**: AgriApp supplies whole information on crop cultivation, crop protection and each one related agriculture allied services. It too enables farmers to avail complete knowledge associated with "High value, low product" kind of crops from varieties, soil/ climate, to harvest and storage measures. A choice to communicate with experts, video based education, news, online markets for insecticides; fertilizers etc. are accessible on the application.
6. **Kheti-badi:** 'Kheti-Badi' may be a social proposal application. It assists to push and help 'Organic Farming' and give relevant information/issues associated with farmers in India. Agriculture now-a-days is highly infatuated with genetically modified seeds, fertilizers and chemical pesticides; this application assists farmers towards switching their chemical farming into organic farming. However, this application at present is only available in three languages (Hindi, English and Marathi).
7. **Krishi Gyan:** Krishi Gyan Works on the identical aspect as Whatsapp communication but is taken into consideration to be better because it doesn't require mobile numbers of individuals to stay connected. Aside from supplying common information on farming, it enables Indian farmers to attach with Krishi Gyan experts and enquire questions associated with farming, and search answers inside the applying through notifications. The farmers in addition as agriculture enthusiasts can still share their answers with each other.
8. **Crop Insurance**: The application assists farmers to analyse premium for notified crops and provides information points in time and company contacts for his or her crop and site. It can also be accustomed to get particulars of the regular sum insured, premium details, extended sum insured and subsidy information of any notified crop in any notified area. It's further linked to its web portal which caters to all or any or any stakeholders including farmers, states, insurance companies and banks.
9. **AgriMarket:** It was launched alongside the Crop Insurance application by the Government of India, the application was developed with an intention to remain farmers on top of things crop prices and dispirit them to travel for distress sales. Farmers can acquire information linked to values of crops in markets inside 50km of their smartphone location with the AgriMarket Mobile Application.
10. **Bhuvan Hailstorm App**: - This mobile app can capture the photograph of the field with latitude and longitude, name of the crop, date of sowing, date of likely harvesting, and source of irrigation.
11. **Plantix** - Plantix is a mobile app for plant disease diagnostics and monitoring. Plantix offers the possibility to send pictures of affected plants directly via smartphone and guides through an identification process to determine the plant disease in a very simple manner. All pictures sent via the Mobile App are tagged with coordinates, which enables real-time monitoring of pests and diseases.
12. **eNAM Mobile App** - It is used to facilitate remote bidding by traders and access to arrivals and price-related information to farmers and other stakeholders on their smartphones.
13. **riceXpert** - This app Provides real-time diagnosis of insect pests, diseases, nematodes, weeds, nutrient deficiencies, and toxicities to farmers. It has other features like rice varieties, agricultural implements, news, expert consultation through the e-advisory services module, and weather information.
14. **Pashu Poshan** - With the help of this app, a balanced ration can be formulated while optimizing the cost by considering animal profile, i.e. cattle or buffalo, age, milk production, milk fat, and feeding regime, etc., and

milk producers are advised to adjust the quantity of locally available feed ingredients offered to their animals along with the mineral mixture.

15. **Cattle Expert System** - It covers feeding management for cattle and buffalo, breeding management, disease and control management, production technology, calf management, general care and management, practices, etc. for cattle and buffalo.
16. **Dairy Telugu and Dairy Kannada** - These apps are equipped with analytics and a decision support system with language support. The mobile app content is presented in the form of interactive audio-video content, to help farmers understand easily.
17. **mKrishi Fisheries App** - INCOIS generates Potential Fishing Zone (PFZ), a fish shoals prediction information based on the remote sensing data received from NOAA satellites, sea surface temperature, and the presence of phytoplankton which form the food of several fish species. The app consolidates this information and presents advisories in the local language.

Conclusion:

The smartphone is now being widely used by farmers both as a source of information and as a medium to obtain information regarding farming to make better decisions. All these mobile applications help to reduce transportation, middlemen and transactional waste in agriculture. These applications are helping to boost overall business performance and reducing the negative environmental impacts of farming. Any kind of information is one click away for the farmers recently. However, sseveral new mobile applications are being introduced regularly, so it is highly important to select which application to use by checking if the applications provide up to date information with credibility and fulfilling all the requirements of the farmers.

References:

Singh N.K., Sunitha N.H., Tripathi G., Saikanth D.R.K., Sharma A., Jose A.E., et al. Impact of Digital Technologies in Agricultural Extension. Asian J Agric. Ext. Econ. Soc. 2023; 41(9):963-970.

Saikanth D.R.K., Karuna Jeba Mary, Ashish Kumar Nagar, Rishabh Yadav, Abhijeet, P Thilagam and Shubham Singh. Mobile applications for agricultural transformation: Types, impacts, case studies, and recommendations. International Journal of Statistics and Applied Mathematics 2023; SP-8(6):405-414.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

CROP RESIDUE MANAGEMENT: STRATEGIES FOR SUSTAINABLE AGRICULTURE

Jyoti Khatkar[1], Anil Kumar[2] and Parveen Kumar[1]

[1]Department of Soil Science, Chaudhary Charan Singh Haryana Agricultural University, Hisar

[2]Department of Agronomy, Chaudhary Charan Singh Haryana Agricultural University, Hisar

Introduction

India is confronted with a number of agricultural issues in order to maintain soil fertility and food crop production. Food grains are essential for food and nutritional security since they are a significant source of energy. Global food production has increased dramatically as a result of the rising need for food in many nations. The extensive use of external inputs is essential to the present intensive farming system. According to reports, one of the most promising ways to address this issue is to gradually move away from the use of chemical fertilizers and toward the use of various organic manures and conventional plant nutrient elements (composts, yard manure, etc.). crop leftovers are typically regarded as waste material in terms of their economic significance. Crop residues, however, present a number of viable nutrients recycling pathways, including soil carbon sequestration. Crop leftovers contribute to plant nutrients and provide soil microbes with organic carbon. Keeping crop leftovers on the soil surface lowers runoff, soil erosion, soil evaporation, and the expense of land preparation. According to a Ministry of New and Renewable Energy assessment on agricultural leftovers, India generates 500 million tons (Mt) of crop residues annually.

Why we needed for crop residue management?

Crop residue management since farmers, mostly from India, burned their crop wastes. Approximately 730 Mt of biomass are burned annually in Asia, with 18% of that amount occurring in India. Burning crop residue results in the following problems.

Loss of nutrients

In general, crop residues of various types are thought to include 20% potassium (K), 50% sulphur (S), 25% phosphorus (P) and 80% nitrogen (N). According to estimates, burning one tonne of agricultural residue results in the loss of 5.5 kg of nitrogen, 2.3 kg of phosphorus, 25 kg of potassium, and 1.2 kg of sulfur. In addition, there is a total loss of organic carbon, and increases greenhouse gas emissions, which causes climate change. The soil becomes enriched with the mentioned nutrients, especially organic carbon, and provides food for soil microorganisms and plant nutrients if agricultural leftovers are integrated or preserved in the soil.

Impact on soil properties

Beneficial soil organisms die when the heat from burning wastes raises the soil's temperature. The microbial population is completely destroyed by frequent residue burning, but this is only a short-term effect because the microorganisms return within a few days. The upper (0–15 cm) soil layer's levels of N, C, and maybe mineralizable N are also decreased by frequent field fire.

Emission of greenhouse gases (GHG)

Greenhouse Gases (GHGs) are released in large quantities when crop residues are burned. While 2% of the nitrogen in rice straw is released as nitrous oxide (N_2O) when it burns, roughly 70%, 7%, and 0.7% of the carbon present in the straw is released as carbon dioxide (CO_2), carbon monoxide (CO), and methane (CH_4), respectively. As a result, Emissions of greenhouse gases increased.

Crop residue – types

Field residues

Field residues are the leftovers from harvesting a crop that are left in an agricultural field. These leftovers consist of seed pods, leaves, stalks, and stubble. The residue can either be burned first or ploughed straight into the ground. On the other hand, reduced tillage, strip tillage, or no-till farming methods are used to increase crop residue cover. Effective field residue management can improve irrigation effectiveness and reduce soil erosion.

Process residues

Materials that remain after the crop has been transformed into a useful resource are known as process residues. Husks, seeds, bagasse, molasses, and roots are some examples of these leftovers. They can be utilized in manufacturing, as well as fertilizers, soil amendments and animal feed.

Challenges for management of crop residue

- Huge volume of crop residue, Collection & Storage.
- Time window between harvesting and sowing of two(next)crops.
- Cost-effective mechanization, awareness and availability of appropriate machinery.

Management of crop residues

Balling and removing the straw

Agriculture-related surplus straw can be utilized for a variety of beneficial applications, including building materials, livestock bedding, fuel, animal feed, and composting for mushroom cultivation. One of the most promising uses of forest and agricultural waste is mushroom development. Mulching for orchards and other crops, and bedding for veggies like cucumbers, melons, etc.

Soil mulch

A technique known as "direct drilling in the surface mulched residues" leaves agricultural residues from a prior crop on the soil's surface without incorporating them in any way. Surface retention of residues helps to protecting the fertile soil surface against wind as well as water erosion. In areas where conservation tillage or no-till methods are common, farmers typically employ these techniques. It inhibits the growth of weeds. While preventing erosion of the top 5 to 15 cm of soil, residues increase the amount of organic carbon and total nitrogen in the soil by slowly breaking down on the soil surface. Crop residue increases microbial activity, soil C, N and lowers fertilizer N requirements for rice. On the one hand, it provides habitat for both beneficial and detrimental organisms. It supplies C substrate for heterotrophic N-fixation. If this is prepared with urea and applied during field preparation, nitrogen can decompose and release into the soil more quickly.

Crop residues incorporation

Crop leftovers can either be fully or partially integrated into the soil, depending on the cultivation technique. Crop output can be increased by incorporating straw. The most effective way to incorporate residue is by ploughing. It is more difficult to incorporate rice residues before planting wheat than it is to incorporate wheat straw before planting rice because of the low temperatures and short days between rice harvest and wheat sowing. Crop leftovers are a valuable source of organic matter that can be recycled into soil to improve its physical, chemical, and biological qualities. They are rich in organic carbon and mineral nutrients.

Crop Residues for Improving Input Use Efficiencies

Improving Soil Physical Properties

It has been demonstrated that adding leguminous crops improves the physical characteristics of the soil, including its permeability and ability to hold water. By improving the availability of nutrients for the crop's root zone, the addition of leguminous crop wastes also boosts crop growth and yield. The soil's porosity and water-holding capacity can be greatly increased by applying agricultural residues made from ryegrass, straw, and mixed litter. This will ultimately increase the soil's productivity. In rice-based farming systems, it has been shown that applying crop leftovers in conjunction with conservation tillage enhances soil aggregate and carbon storage.

Improving Soil Chemical Properties

The chemical characteristics of soil, such as pH, electrical conductivity, and cation exchange capacity (CEC), as well as the conversion of various primary and secondary plant nutrients, can be effectively enhanced by sustainable crop management. The application of crop residue is positively correlated with the soil carbon pool (both the total and labile pool). According to reports, an irrigated maize production system's total and labile carbon pool can be considerably increased by applying 75 kg N ha^{-1} in addition to 10 Mg ha^{-1} of wheat residue mulching. By recycling up to 15% of the soil's available K, residue integration also helps to reduce the need for external K supplies.

Improving Soil Microbial Activity

The control of soil microbial biomass is significantly impacted by the appropriate retention of crop wastes. Applying crop residue mulching may promote microbial activity in the top layer of soil by changing the plant-soil microclimate, increasing the availability of water and nutrients, and regulating soil temperature. In comparison to the control treatment (which applied crop residue), it has been observed that adding residues of leguminous crops, such as cluster beans, prior to planting the next crop increases soil microbial biomass and dehydrogenase activity (DHA).

Improving Soil Productivity

Utilizing soil nutrients and preserving soil productivity are greatly aided by appropriate crop residue management. Improved soil production and nutritional status are two benefits of effective crop residue management. It has been noted that applying crop residues over an extended period of time in conjunction with conservation tillage increases soil productivity, the C-pool, and the earthworm population.

Crop Residues Improve the Fertility and Productivity of Soil

The natural ability of soil to maintain a sufficient supply of nutrients for plants is known as soil fertility, and it can be determined by chemically analysing the soil. However, crop yield can be used to measure soil productivity, which is the combined outcome of field conditions involving soil fertility and management parameters. The physical, chemical, and biological characteristics of soil that are inherently related to the soil's organic matter stock are closely related to soil fertility. Healthy food production, preserving long-term soil fertility, and environmental sustainability have all received increased attention recently. Other factors include conserving natural resources, increasing productivity through proper land and soil management, recycling residues, precision technology and supplying more plant nutrients from organic sources rather than inorganic ones.

Conclusion

Crop residue improves the physical, chemical, and biological qualities of soil over time. By incorporating crop leftovers into the soil, proper nitrogenous fertilizer management techniques may reduce nitrogen immobilization. No tillage technique that is appropriate for the site and soil type may be utilized. The greatest solution for sustainable agriculture is to incorporate crop leftovers into the soil and use environmentally friendly management techniques.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

AMBERGRIS: THE FLOATING GOLD

Darren Jeeth Fernandes, Sachin Dnyanoba Chavan, Dalsaniya Bhavy Anilbhai

Karnataka Veterinary, Animal and Fisheries Sciences University, Bidar, College of Fisheries, Mangaluru, Karnataka (575 002)

Abstract

Ambergris, a rare and valuable biomaterial produced by sperm whales (*Physeter macrocephalus*), has been historically significant in luxury perfumery, pharmaceuticals and personal care industries due to its distinct chemical properties. This article examines its formation, physical & chemical characteristics and evolving regulatory frameworks governing its trade. The widely accepted intestinal secretion theory suggests that ambergris originates as a protective response to indigestible squid beaks, undergoing photodegradation & oxidation post-expulsion to develop its unique olfactory profile. Despite its economic & industrial relevance, conservation concerns have led to stringent legal restrictions in several nations, including Australia, the United States and India, with enforcement mechanisms focusing on wildlife protection. Current research explores synthetic alternatives to replicate ambergris's sought-after fragrance and fixative qualities.

Keywords: Ambergris, Floating gold, Sperm whale, Grey amber, Perfume.

Introduction

Ambergris, also known as "grey-amber" in French, is a waxy material that comes from the largest toothed whale species, commonly known as sperm whales (*Physeter macrocephalus*). There are various theories on how the ambergris originates. Although it is incorrectly referred to as "whale vomit", the reason being that it was initially thought to be the regurgitation of the sperm whale when the undigested parts of the squids & cuttlefish i.e. its beaks and pens, are surrounded or coated with a fatty, cholesterol-rich substance which served as a protection in the gastrointestinal tracts of the sperm whales.

Figure 1: Photograph of ambergris by David Liittschwager, National Geographic

The ambergris has a colour range from black to pale white or gray. The white coloured ambergris is more valuable & expensive. With the progress of time, the ambergris becomes light & pale with age, this is due to the exposure of the same to the air & sea water (**Srinivasan, 2015**). It has a redolent profile & its scent evolves over time as it matures. The freshly harvested ambergris has a mix of pungent as well as a putrid sea odor, however, as it matures, it develops a well-balanced fragrance with musky, animalic, marine, sweet, earthy & woody fragrance notes (**N He et al., 2024**).

The sperm whale species that have been a part of the historical whaling, because of its large oil reserves or spermaceti oil & the ever-valuable ambergris had their numbers drastically reduced (**Tillman, 1983**). Due to this heavy whaling pressure observed during this period, these whale species are now being protected in most of the nations around the world.

Sources of Ambergris

There are several theories that are associated with the sources of the ambergris. The widely accepted theory for the source of ambergris is the Intestinal Secretion theory which suggests that the ambergris is formed in the intestines of the sperm whales as a reaction to the indigestible squid beaks obtained through its diet. It is believed to form a protective secretion, eventually being expelled by the whale (**Kemp, 2012**). The other theory associated with ambergris is the Pathological secretion theory where some of the researchers have suggested that the ambergris is a pathological secretion resulting from an illness or irritation in the whale's digestive system.

Figure 2: Sperm whales (Physeter macrocephalus) by © Stas Zakharov (iNaturalist)

Physical properties

Ambergris is typically found in lumps of various forms and sizes that range in weight from 15 grams (12 ounce) to 50 kilograms (110 pounds). Most of the ambergris specimens observed exhibit an irregular, rounded solid shape, but they decompose quite easily (**Brito et al., 2016**). During the first expulsion or when the ambergris is found on the whale, the fatty precursor of ambergris exists in the form of a soft, creamy white substance, that is occasionally streaked with black stripes also while possessing a characteristic fecal odour. Over the period of a few months to years due to the process of photodegradation & oxidation in the water, this precursor eventually hardens thereby taking on a dark grey or black shade with a crusty & waxy texture that is accompanied by a peculiar fragrance. This fragrance has a striking blend of sweetness, earthiness, marine depth & a distinct animalic undertone. The fragrance is usually characterized as being a significantly more sophisticated & softer version of isopropanol, without its pungent harsh character (**Yamabe et al., 2020**). Ambergris in its evolved form, has a specific gravity between 0.780 & 0.926, which shows its ability to float on water. When it is exposed to a temperature of about 62 °C (144 °F), it becomes a viscous yellow resinous liquid and when it is increased to about 100 °C (212 °F), it evaporates in the form a white vapor. Additionally, it exhibits solubility in ether, as well as in aromatic & fixed oils.

Chemical properties

The ambergris exhibits a minimal reactivity to acid solutions. The terpene ambrein, which was reported first in 1946 by Ruika & Fernand Lardon, can be purified & extracted from crude ambergris by subjecting ambergris to heating in alcohol, then allowing the solution to be cooled thereby allowing its characteristic white crystals to precipitate. Ambergris primarily consists of two main constituents, i.e., the cholestanol-type steroids, which form about 40 to 46% of its overall composition and ambrein, a triterpenoid present in concentration range of 25 to 45% (**Ncube et al., 2020**). When this ambrein, which is basically odorless, is oxidized, it is converted to ambroxan & ambrinol. These compounds are the chief contributors to the characteristic odor emanating from the ambergris.

What are the uses of ambergris and why is it so expensive?

Ambergris is valued around Rs.1-2 crores per kilogram in India, depending on the purity and quality, according to investigating authorities from across India who have recently seized it. Its trade is banned in around 40 nations, including India, under the Wildlife Protection Act, 1972, yet demand persists in the Middle East, Europe and Southeast Asia. Reports also suggest its use as an aphrodisiac & in medicinal treatments.

Uses of Ambergris

1. Fragrance & Perfume Industry

Ambergris is a highly coveted ingredient in luxury perfumery, valued for its distinctive scent profile and exceptional fixative properties (Srinivasan, 2015). It plays a crucial role in enhancing fragrance longevity and depth, making it a sought-after component in high-end perfumes. The increasing global demand for exclusive and natural ingredients continues to fuel its market growth, reinforcing its status as a premium element in elite fragrance formulations.

Ambergris is an unusual ingredient & organic fixative in perfumery. Its ability to blend with citrus, floral, creamy & woody accords make it contribute freshness combined with enduring depth. This balancing ingredient enables a scent to develop over time from an invigorating first impression to a rich, long lasting foundation, thereby making ambergris a sought-after material in the creation of refined fragrance structures.

2. Pharmaceutical Industry

Ambergris has historically been valued for its medicinal properties, including anti-inflammatory and antiseptic benefits. Recent research in this industry is focused on investigating the potential alternative uses of ambergris in the development of therapeutic compounds that facilitate wound healing & aging deceleration. This makes it useful in discovery of novel drug. As the market continues to be develop a interest in these natural & effective products, the demand for ambergris also rises, thereby unveiling its potential in the innovative health solutions (Wang et al., 2024, Brito et al., 2015).

3. Food & Beverage Industry

Occasionally the ambergris is used as a flavoring agent, lending a distinctive musky aroma to a variety of the gourmet dishes. Even though it is not being directly used in the preparation of the food products, there may be time which may lead to further experimentation in the culinary setting owing to the surge of interest of people in trying out rare & exotic foods. However, the regulations on the sourcing, trade & moral considerations still present a significant hurdles to its application on a grand scale for the use in food products.

4. Personal Care & Cosmetics

In the recent times, the ambergris is also being utilized in the lotions & creams, thereby capitalizing on its natural as well as luxurious appeal. Its rarity & distinctive properties make it a desirable as well as a highly valuable ingredient in the high end skincare products. This is aligned with the growing consumer preference for organic & unique formulations.

Legalities and recent cases of seizure in India

The possession of ambergris and its sale is illegal & is banned in most of the countries, including the United States of America, Australia and India. However, it is legal in some of the countries, though under strict constraints. In India, the sperm whales, which produces the ambergris, are included in the Schedule 2 of the Wildlife Protection Act of 1972 (Ministry of Law and Justice, 1972), under which the possession or sale of any of their by-products, is strictly banned. Some of the recent cases that involve the illegal trade of ambergris are mentioned below:

Mysuru, May 2023: In the city of Mysore, Karnataka, the police apprehended three individuals from Kerala who were transporting 9.821 kg of ambergris, that was valued at approximately ₹18 crore. The suspects were intercepted & apprehended while they were moving towards Bengaluru. The investigations revealed that the ambergris had been procured from the local fishermen in Kerala, highlighting the ongoing illegal trade activities despite its prohibition (May 23, 2023, Times of India).

Kodagu, April 2025: A covert police operation near Heggala Junction, Kodagu, Karnataka led to the seizure of 10.390 kg of ambergris, worth approximately ₹10 crore. Ten individuals were arrested, with investigations revealing links to smuggling networks spanning Kerala, Bengaluru and Andhra Pradesh (Apr 10, 2025, Times of India).

Ahmedabad, May 2025: The Detection of Crime Branch (DCB) of Ahmedabad City Police seized 2.904 kg of ambergris, valued at ₹2.9 crore and arrested four individuals. The suspects were attempting to sell the substance illegally, violating the Wildlife Protection Act (May 09, 2025, Indian Express).

Countries where the sale of Ambergris is deemed illegal

- **Australia**: The Environment Protection and Biodiversity Conservation Act (1999) prohibits the commercial export and import of ambergris.
- **United States**: The Endangered Species Act (1973) strictly prohibits the trade and possession of ambergris.
- **India:** The Wildlife (Protection) Act (1972) forbids both the sale and possession of ambergris.

Countries where the sale of Ambergris is deemed legal

- **United Kingdom**: Ambergris is regulated under the standard commercial & cosmetic laws, avoiding the restrictions from its ban on the protected species.

- **France**: It is treated as a naturally secreted byproduct and is permitted under the cosmetic regulations.
- **Switzerland**: Trade is allowed with mandatory documentation and traceability to ensure legal sourcing.
- **Maldives**: The commercial use is permitted under the maritime law when ethical sourcing standards are maintained.

Conclusion

Ambergris is a rare & a highly valued substance with a rich scientific & historical significance. Its origin within the sperm whales, coupled with its transformation into a fragrance enhancing compound, makes it a prized ingredient in the luxury perfume, pharmaceutical & the personal care industries. However, the scarcity of this ambergris, coupled with the ethical concern for the conservation of these whale species, has made it necessary to impose legal controls to conserve the population of the sperm whale. Despite the implementation of several regulatory barriers, ambergris still remains a highly sought after material because of its unique smell profile and fixative nature. The United Kingdom, France, Switzerland & the Maldives still permit its sale, thus testifying to its popularity in the niche markets. Ongoing scientific research exploring synthetic alternatives and ethical sourcing methods may shape its future use, potentially offering sustainable solutions that preserve its coveted attributes while mitigating conservation concerns.

Reference

Srinivasan, T. M. (2015). Ambergris in perfumery in the past and present Indian context and the western world. Indian Journal of History of Sciences, 50(2), 313.

He, N., Yu, H., & Ye, L. (2024). Efforts toward ambergris biosynthesis. Chem & Bio Engineering, 1(2), 91-98.

Tillman, M. F. (1983). Special issue on historical whaling records. International Whaling Commision.

Kemp, C. (2012). Floating gold: A natural (and unnatural) history of ambergris. University of Chicago Press.

Brito, C., Jordão, V. L., & Pierce, G. J. (2016). Ambergris as an overlooked historical marine resource: its biology and role as a global economic commodity. Journal of the Marine Biological Association of the United Kingdom, 96(3), 585-596.

Yamabe, Y., Kawagoe, Y., Okuno, K., Inoue, M., Chikaoka, K., Ueda, D., Tajima, Y., Yamada, TK., Kakihara, Y., Hara, T, & Sato, T. (2020). Construction of an artificial system for ambrein biosynthesis and investigation of some biological activities of ambrein. Scientific Reports, 10(1), 19643.

Ncube, E. N., Steenkamp, L., & Dubery, I. A. (2020). Ambrafuran (AmbroxTM) synthesis from natural plant product precursors. Molecules, 25(17), 3851.

Wang, B., Liu, Y., Jia, C., Lan, Z., & Yang, X. (2024). A Concise Synthesis of (−)-Ambrox. ChemistryOpen, 13(9), e202400006.

Ministry of Law and Justice (India). (1972). The Wildlife Protection Act, 1972. Government of India.

Virgili, A. (2018). Modelling distributions of rare marine species: the deep-diving cetaceans (Doctoral dissertation, Université de La Rochelle).

https://www.nationalgeographic.com/animals/article/120830-ambergris-charlie-naysmith-whale-vomit-science

https://www.inaturalist.org/observations/114934677

https://timesofindia.indiatimes.com/city/mysuru/mysuru-police-seize-ambergris-worth-rs-18-crore-arrest-three-from-kerala/articleshow/100443042.cms

https://timesofindia.indiatimes.com/city/mysuru/ambergris-worth-rs-10-crore-seized-in-kodagu/articleshow/120172596.cms

https://indianexpress.com/article/cities/ahmedabad/sperm-whale-vomit-ambergris-worth-rs-2-9-crore-seized-in-ahmedabad-four-arrested-9975627/

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Cashew Nut Processing: From Farm to Consumer

Sunil C[1], Jeevan H R[2], and Umme Seema N[3]

[1]Department of Agronomy, Senior Scientist & Head, ICAR-KVK, KSNUAHS, Shivamogga, India

[2]Department of Agronomy, Research associate, cashew technology centre, KSNUAHS, Shivamogga, India

[3]Department of Post Harvest Management, Research Associate, Cashew technology centre, KSNUAHS, Shivamogga, India

Introduction

Cashew is one of the important tropical crops called as "poor man's crop, rich man's food". The cashew nut is native of Brazil from where Portuguese travelers took the cashew plants to India. In India Cashew plant first recorded in Cochin by 1578, in Goa by 1598. The crop is grown mainly in peninsular states of India particularly along the coastal states like Kerala, Karnataka, Goa, Maharashtra, Tamil Nadu, Andhra Pradesh, Orissa and West Bengal. India processed about 1.18 million MT of raw cashew seeds through 3650 cashew processing industries scattered in many states of country and providing employment to over half million people. The cashew industries in India employed different methodology for processing. It depends on the variety of raw material, location, technological mechanization and availability of secured energy supply. Processing of cashew is defined as the recovery of edible meat portion- the kernel from raw nuts, by manual or mechanical means.

Home-scale nut processing, particularly of cashew nuts, often involves a combination of manual labour and basic equipment. While factory-scale processing utilizes automated machinery, home processing typically relies on techniques like; 1. Drying of freshly harvested raw kernels for storage, 2. Grading of cashew nuts based on shape colour and size, 3. Steam Boiling /cooking, 4. Shelling, 5. Drying, 6. Weating/moisturising, 7. Peeling, 8 Grading, 9. Drying, 10. Packing/Packaging

1. Drying of freshly harvested raw kernels for storage

Drying cashew nuts is a crucial step in processing to reduce moisture content, prevent spoilage, and enhance shelf life. Sun drying, where the nuts are spread out in the sun for several days, is a common method, but mechanical dryers can be used in regions with high humidity. The goal is to achieve a moisture level below 9 Percent.

Fig 1: Sun drying of cashew nuts

2. Grading of cashew nuts

Grading of harvested kernels involves sorting and classifying them based on various physical and sometimes chemical or biological characteristics like shape, color, moisture content, and the presence of defects (e.g., void nuts, immature nuts, damaged nuts). to separate them into different quality categories. This process is crucial for ensuring high-quality kernels is used for processing and avoiding the use of low-quality material.

Fig 2: Grading of cashew nuts

3. Roasting /Steaming

There are two commonly followed methods of cashew nut processing such as Steam cooking process and Roasting process.

Roasting is mainly designed to make shell brittle. there are 3 methods of roasting.

a. Open Pan Roasting

The earliest process was the pan roasting wherein the nuts are heated on a metal pan over an open fire. Due to the heat and slight charring the shells become brittle. The pan roasting is not followed in organized sectors of industries. The two important methods of processing now adopted are; a. Drum roasting and b. Oil bath roasting.

b. Drum roasting

The nuts are fed into a rotating hot drum, which ignites the shell portion of the nut. The drum maintains its temperature because of the oil oozing out of the nuts. The drum is kept in rotation by hand for about 2-4 minutes. The roasted nuts which are still burning are covered with wood ash to absorb the oil on the surface. The rate of shelling and the outturn of whole kernels are very high in this method. However, the main disadvantage is the loss of CSNL which has a very high export potential. In addition there will be considerable heat and acrid fumes in the vicinity of this operation.

c. Oil bath roasting

In this method, the nuts are held in wire trays and are passed through a bath of cashew shell oil maintained at a temperature of 200-202^{o}C for a period of three minutes whereby the shell oil is received from the shells to maximum possible extent. The vessel is embedded in brick work and heated by a furnace which use spent shell as fuel. During roasting, the shell gets heated and cell wall gets separated releasing oil into bath. As the level rises the oil is recovered by continuous overflow arrangement. The roasted nuts are then converted into a centrifuge. The residual oil adhering to the surface of nuts is removed by centrifuging. The roasted nuts are mixed with wood ash and sent for shelling. The well dried nuts are hand shelled. Here also the CSNL is completely recovered.

Steaming

This method now a day's adopted widely all over India. The dried nuts are steam cooked. Well dried raw nuts are subjected for steam boiling which is commonly adopted method of nut conditioning in India. Steaming is a crucial step in cashew processing, specifically designed to soften the hard outer shell and release the cashew kernel inside. This process involves subjecting raw cashew nuts to high-pressure steam, which expands the shell and hardens it, making it easier to crack and remove the kernel. The raw nuts are steamed conditioned about 100-120 lb pressure for 15-20 minutes and then allowed for 24 hrs cooling.

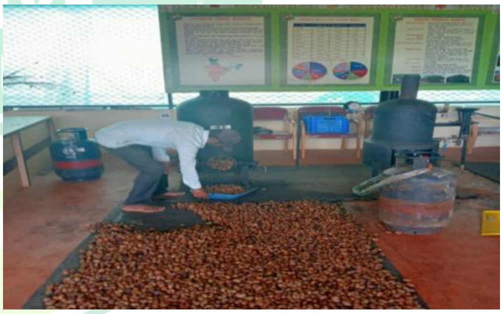


Fig 3: Steaming

4. Shelling

Cashew shelling is the process of removing the cashew nut from its hard outer shell. This is a crucial step in cashew processing, as the outer shell contains a toxic oil. Both manual and mechanical methods are used, After Steaming raw nuts after conditioning and cooling are to be shelled to remove kernels with the help of hand cum pedal operated shell cutter. or with the help of semi-automatic cutter the kernels and shell pieces are separated manually immediately after cutting.

Fig 4: Hand cum pedal operated shell cutter

Fig 5: Semi-automatic cutter

ISSN : 3048 - 989X

5. Drying

After shelling, kernels contain brown peel over it, known as testa.it contains more than 10% of moisture. To remove testa over the kernel and also control the moisture content in the kernels, they are exposed to prolonged and controlled heating with perforated tray dryer at 65-70 degree centigrade for about 6-7 hrs in the chamber. Before moisturising about 4 –5% of moisture is removed from the kernels in the process.

Fig 6: Drying of cashew kernel

6. Weating/moisturising

Moisturizing the cashew testa (skin) before peeling is crucial for preventing breakage and making the testa easier to remove. This is typically done by carefully humidifying the kernels, either moisturising machine for 2 hr or kernels are spread out on cement flooring then covered wet cotton cloth for 3hr so that they may absorb some moisture and become less brittle. This prevents the tendency to break easily during peeling.

Fig 7: Moisturising by wet cotton cloth

Fig 8: Moisturising by moisturising machine

7. Peeling

Peeling is the removal of testa from the kernels. This is done with help of peeling machine around 90 to 95 % peeling is done here, reaming 5 to 10 are peeling is done by using small hand knife. Peeling is made easier when the kernels are subjected to a heat treatment for about 7 hrs in a drying chamber followed by 2hr moisturising.

Fig 9: Peeling

8. Grading

The next stage of processing is the grading of kernels. primarly raw cashew nuts are graded based on size, shape, color, and presence of defects, later nuts are graded on the basis of specifications for exportable grades. There are 25 exportable grades of cashew kernels. The kernels are graded into wholes, splits and Broken primarily on the basis of visual characteristics. The wholes are again size-graded on the basis of the number of kernels per 1Ib. The entire grading operation is done manually. However for size-grading mechanical operation is also practiced.

ISSN : 3048 - 989X

Specification for cashew kernels

Grade designation	Number of kernels per lb	Grade designation	Number of kernels per lb
W 180	375 to 395	W 320	660 to 705
W 210	440 to 465	W 400	770 to 880
W 240	485 to 530	W 450	880 to 990
W 280	575 to 620	W 500	990 to 1100

Fig 10: Grading of cashew kernels

9. Drying

Cashew kernels need to be dried properly before packing. Drying cashew nuts after grading is a crucial step to prevent spoilage and ensure high-quality cashew kernels. Raw cashews have a high moisture content, which can lead to mold and discoloration. Sun drying, mechanical drying, or hot air drying are common methods used to reduce the moisture to around 6-7%.

Fig 11: Drying cashew nuts after grading for 2 hr

10. Packing

Cashew nuts are typically packed using either vacuum packaging or tin cans, with vacuum packaging becoming increasingly popular due to its cost-effectiveness and shelf-life benefits.

Vacuum packaging is an effective method for preserving cashew nuts, maintaining their shelf life and freshness. By removing oxygen from the packaging, it inhibits the growth of spoilage organisms, prevents oxidation and protects the nuts from moisture and odors.

Fig 12: Vacuum packaging

ISSN : 3048 - 989X

Flow chart of home scale Cashew nut Processing

Sun drying of freshly harvested raw cashew kernels for 5 to 6 days

↓

Grading of kernels based on shape, color, moisture content, and the presence of defects

↓

The raw nuts are steamed cooked/boiled for about 90-100 lb pressure for 15-20 minutes and then allowed for 24 hrs cooling.

↓

Shelling of kernels with the help of hand cum pedal operated shell cutter. Or with the help of semi-automatic cutter then the kernels and shell pieces are separated manually.

↓

Drying of cashew kernel for 7hr at 70^{o}c

↓

Then kernels are moist for 2 hr using moisturising machine, or kernels are spread on wet cotton cloth for 3hr

↓

Peeling is done with help of peeling machine or hand peeling

↓

Cashew nuts are graded based on size, shape and color,

↓

Drying of Cashew kernels for 2hr after grading

↓

Packaging

↓

Storage

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

"Short-Term Gain, Long-Term Pain? Choose the Soil-Friendly Path" Short-term fertilizer can give yield, but only soil health ensures sustainability

Pradeep Kumar, Angad Singh Rajput and Purnendra Dev Verma

Krishi Vigyan Kendra Bhatapara, Chhattisgarh

"Do we feed our crop directly, or do we nurture the soil that feeds it?"

This simple question holds the key to the future of sustainable agriculture.

In most farming systems today, the first instinct of a farmer is to reach for a bag of fertilizers. As soon as the field is ready, urea, DAP, or potash are applied with the expectation that the crop will grow lush and yield abundantly. Indeed, there is no denying that fertilizers give quick results. They supply essential nutrients directly to plants, and farmers can visibly see their crops responding with greener leaves and better growth. This is why most farmers focus on "feeding the crop" rather than thinking about the soil. But is feeding the crop alone the true recipe for long-term success? The answer is – not entirely. Fertilizers are like quick energy supplements. They boost growth for a season, but they cannot replace the foundation of plant health: the soil. Just as no child can remain healthy for long on supplements alone without wholesome food from the mother, crops too cannot rely solely on chemical fertilizers if the soil underneath is deteriorating.

Soil is not just a medium to anchor roots; it is the living "mother" of the crop. When the soil is fertile, rich in organic matter, and teeming with microbes, it provides nutrition naturally, season after season. But when soil health is neglected, the result is evident: declining productivity despite increasing fertilizer use. Farmers today often observe that where once 50 kg of urea was enough, now 80–100 kg is required to get the same yield – and sometimes even that does not work. This is a warning signal that the soil's natural fertility is weakening. Continuous neglect has led to reduced organic matter, micronutrient deficiencies (like zinc, boron, and iron), soil compaction, and poor structure. Fertilizers alone cannot correct these issues. They may feed the crop temporarily, but they do not restore the soil. Without a healthy soil base, even the most advanced crop management practices will struggle to give results.

A healthy soil, on the other hand, is like a caring mother. It supplies nutrients slowly and steadily, improves water retention, and fosters beneficial microbes that unlock nutrients and protect plants from stress. If soil is alive and balanced, crops will thrive—even with reduced chemical input. Feeding the soil is therefore not an alternative to feeding the crop; it is the foundation upon which crop nutrition stands. The real challenge of sustainable agriculture lies in shifting our mindset. Instead of asking, *"How much fertilizer does my crop need?"* we should ask, *"What does my soil need to remain healthy and fertile?"* Because when the soil is healthy, the crop will naturally be well-fed. Thus, the opening question is more than rhetoric—it is a guiding principle for the future of farming. *Do we feed the crop for immediate gains, or do we nurture the soil for lasting productivity?* The answer will determine whether our agriculture remains profitable and sustainable, not just today but for generations to come.

Feeding the Crop: The Conventional Approach

The most widely practiced method of farming today is what we may call the **"crop-first approach."** In this system, the farmer's priority is to apply fertilizers directly to meet the immediate nutritional demands of the crop. As soon as the crop is sown, the focus is on how many bags of urea, DAP, or potash are needed to push the crop toward quick and visible growth.

This approach has dominated modern agriculture for decades, largely because it gives **instant results.** Fertilizers dissolve quickly, are readily absorbed by plants, and show a rapid response. Leaves turn greener, stems grow stronger, and within days the farmer can visibly see that the crop is thriving. For someone looking for quick assurance, fertilizers act almost like a "booster dose" for crops.

Short-term benefits of feeding the crop directly

1. **Rapid growth response** – Nitrogen fertilizers, for example, can turn pale yellow crops into lush green fields within a week.
2. **Higher immediate yields** – When crops get a direct nutrient supply, grain filling and biomass accumulation increase, leading to better harvests in the short run.
3. **Simple to adopt** – Farmers find it easy to measure and apply fertilizers; it is straightforward compared to preparing organic manures or biofertilizers.
4. **Market-driven success** – More yield means more income in that particular season, encouraging farmers to repeat the same practice every year.

Because of these advantages, chemical fertilizers have become the backbone of crop production in almost every farming region.

Limitations of a crop-only focus

While this approach looks attractive in the short run, the hidden **long-term costs** are significant.

1. **Nutrient imbalance**
   - Fertilizer use often focuses heavily on nitrogen and phosphorus, ignoring secondary and micronutrients.
   - This leads to deficiencies of zinc, boron, sulfur, and iron, which affect crop quality and soil health.
2. **Declining soil organic matter**
   - Fertilizers add nutrients but do not replenish organic matter, the "life" of the soil.
   - Over time, soils lose their spongy structure, microbial diversity declines, and the natural nutrient cycle gets disrupted.
3. **Low nutrient-use efficiency**
   - Surprisingly, crops only use 30–50% of the applied nitrogen and 15–20% of the applied phosphorus. The rest is lost to leaching, volatilization, or gets locked in unavailable forms.
   - This means farmers are paying for nutrients that are never fully utilized.
4. **Higher cost of cultivation**
   - With soil health declining, the same crop now requires more and more fertilizer to maintain yield levels.
   - The cost of cultivation keeps rising, squeezing farmer profit margins.

The bigger picture

Feeding the crop directly through chemical fertilizers is like giving a patient energy drinks without addressing the root cause of illness. The crop responds for the moment, but the soil, which should act as a natural nutrient bank, is left depleted. Over time, this leads to a vicious cycle: more fertilizer, less efficiency, higher costs, and stagnant yields. Thus, while the conventional crop-first approach cannot be dismissed—it has undoubtedly helped achieve food security—it is no longer sufficient on its own. The challenge now is to balance crop nutrition with soil care, ensuring that the soil remains a living, fertile foundation for future harvests.

Feeding the Soil: The Sustainable Approach

While feeding the crop with fertilizers provides a quick boost, true sustainability lies in **feeding the soil itself.** Soil is more than just a mixture of sand, silt, and clay – it is a living ecosystem. A teaspoon of healthy soil contains millions of bacteria, fungi, and other microorganisms that work tirelessly to release nutrients, decompose residues, and maintain soil fertility. If the soil is nurtured, it becomes a self-sustaining reservoir of plant nutrition.

What does feeding the soil mean?

Feeding the soil is about providing organic matter, biological activity, and balanced nutrients so that the soil can, in turn, nourish the crop. Instead of simply delivering nutrients directly to plant roots, the focus shifts to building a healthy soil environment that supports plant growth season after season.

Ways to feed the soil

1. **Organic manures and compost**
   - Adding farmyard manure, compost, or vermicompost supplies both nutrients and organic carbon.
   - These inputs improve soil structure, making it easier for roots to penetrate and absorb water and nutrients.
2. **Green manuring**
   - Crops like dhaincha, sunnhemp, or cowpea can be grown and ploughed back into the soil.
   - They enrich the soil with nitrogen, add biomass, and encourage microbial activity.

3. **Crop residue recycling**
   - Instead of burning crop residues, incorporating them into the field improves organic matter and prevents nutrient loss.
   - Residues also protect the soil from erosion and conserve moisture.
4. **Biofertilizers and microbial inoculants**
   - Rhizobium, Azotobacter, Azospirillum, phosphate solubilizing bacteria (PSB), and mycorrhizal fungi make nutrients more available to plants.
   - These eco-friendly inputs reduce the need for chemical fertilizers while boosting soil health.
5. **Balanced use of fertilizers**
   - Even when chemical fertilizers are used, applying them based on **soil test recommendations** prevents overuse and ensures harmony with organic practices.

Benefits of feeding the soil

- **Improved soil health** – Organic matter acts like glue, binding soil particles and improving aeration.
- **Better water retention** – Healthy soils hold more water, reducing irrigation needs and protecting crops during dry spells.
- **Enhanced nutrient availability** – Microbes break down complex compounds into plant-available forms, ensuring a steady nutrient supply.
- **Resilient yields** – Crops grown in soil with high organic matter withstand drought, pests, and diseases better.
- **Long-term productivity** – Unlike fertilizers that give quick but temporary results, soil-feeding practices build a foundation for decades.

Why this approach matters now

Farmers across many regions report that despite using more fertilizers, yields are no longer rising. This stagnation is a clear sign that **soil health has been compromised.** Feeding the soil restores its natural balance and brings back its lost productivity. It also reduces dependency on costly fertilizers, lowering the cost of cultivation. Feeding the soil is like investing in a savings account. Each addition of organic matter, compost, or biofertilizer is a deposit that earns interest in the form of future fertility. Instead of exhausting the soil year after year, this approach nurtures it, ensuring that it remains a fertile and living base for future generations.

Soil vs. Crop – A False Choice

At first glance, the debate seems simple: Should we focus on feeding the crop directly or on nurturing the soil? But the truth is, **this is not an either-or situation.** Crop and soil are inseparably linked – two sides of the same coin. A farmer who looks after the soil is, in fact, automatically ensuring better nourishment for the crop. Similarly, ignoring soil health in the pursuit of higher yields is like trying to build a house on a weak foundation – the results may be quick, but they will not last.

Why soil and crop cannot be separated

- **Soil is the crop's stomach:** Just as food is digested in our stomach before the body absorbs it, fertilizers and organic inputs must pass through soil processes before crops can use them. Without a healthy soil, nutrients remain locked and unavailable.
- **Crop residues feed back into the soil:** Every harvest leaves behind roots, stubbles, and organic matter. If returned to the soil, these residues enrich it for the next crop. Thus, the crop feeds the soil even as the soil feeds the crop.
- **Balanced cycle:** Plants extract nutrients, and soils replenish them when managed properly. Breaking this cycle by only "feeding crops" with chemicals depletes the soil faster than it can recover.

The illusion of short-term gains

Many farmers witness immediate results with fertilizers and assume that feeding the crop alone is sufficient. Yields may rise for a few years, but over time, the soil loses its fertility, water-holding capacity, and biological life. This leads to a situation where even **higher doses of fertilizer fail to increase yield.** In reality, it is not the crop that has become unresponsive – it is the soil that has been exhausted. This is the classic case of **"Short-term gain, long-term pain."** Fertilizers may give quick results, but neglecting soil health gradually reduces productivity and profitability. In the end, farmers spend more but harvest less.

Integrated Nutrient Management: The middle path

The solution lies in striking a balance – using both **soil-feeding practices** and **crop-focused inputs** together. This is where **Integrated Nutrient Management (INM)** comes in. It emphasizes:

1. **Soil testing** before applying fertilizers.
2. **Combining organics and inorganics** – farmyard manure, compost, biofertilizers along with urea, DAP, or MOP in balanced proportions.
3. **Crop rotation and diversification** to reduce nutrient drain.
4. **Use of bio-stimulants like humic acid and microbial inoculants** to revive soil life.

This balanced approach ensures that crops get the nutrients they need immediately, while soils are steadily improved for the future.

Voices from the field

Across India, farmers who once relied solely on chemical fertilizers are now realizing the importance of soil care. For example:

- **Rice-wheat farmers in Punjab** are adopting crop residue incorporation with happy seeders instead of burning residues. Yields have stabilized while soil organic matter is rising.
- **Use of Bio-fertilizer in the District-Balodabazar:** Farmers are increasingly using Rhizobium Azotobacter and PSB cultures, which not only reduce fertilizer costs but also improve soil fertility for succeeding crops. These examples show that the false choice of soil versus crop can be replaced by a **synergistic approach.**


Printed from
THE TIMES OF INDIA

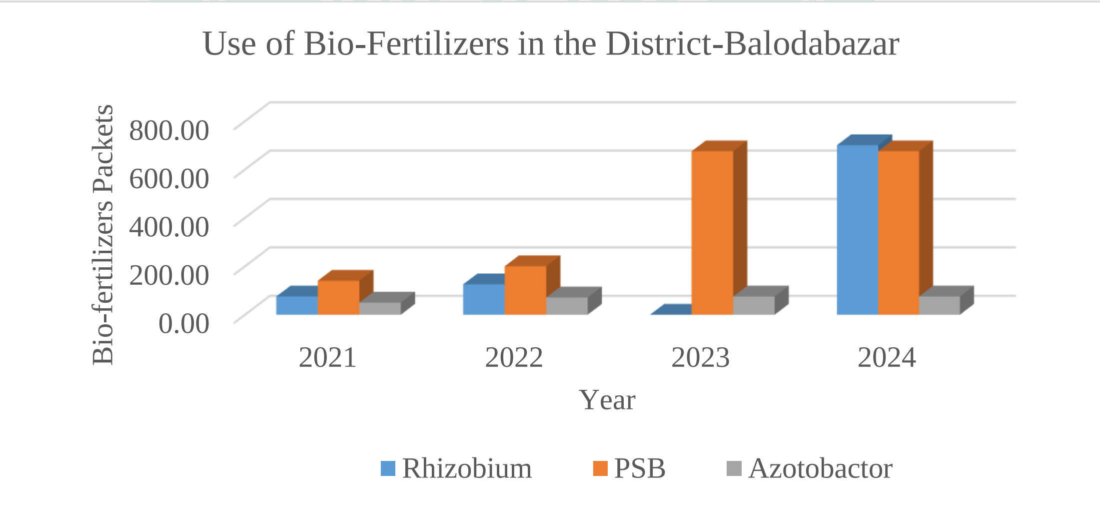
42% CRM machines bought since 2018-19 in Pb are super-seeders

Nov 28, 2024, 04:28 AM IST

Bathinda: Super-seeder has turned out to be one of the most sought-after crop residue management (CRM) machines for wheat sowing during the short window after paddy harvesting. This came to fore in a status report submitted by Punjab agriculture department to National Green Tribunal (NGT) on Tuesday, in an ongoing petition registered suo motu after a news item, 'Pollution takes a front seat as stubble fires spike in Punjab', was published in Oct 2023.

Of all CRMs procured at 50%-80% subsidy since 2018-19, 42% are super-seeders, showed data submitted to NGT. In all, 1,46,549 CRM machines have been provided on subsidy under the central scheme since 2018-19 till date. Of these, 61,951 are super-seeders. As per the field capacity of machines, the number is sufficient to cover the area under paddy in Punjab, stated the department.

Punjab agriculture director in an affidavit has mentioned that village-wise gap analysis was carried out for 2023, in terms of seeding machinery required for sowing area under paddy. According to the report, 22,914 units of machinery were required to bridge the gap between the available and needed machinery, and 9,494 super seeders had been provided on subsidy in 2024.



Instead of asking, *"Should we feed the soil or the crop?"* the real question is, *"How can we feed both in a way that supports each other?"* When soil is nurtured, crops thrive. When crops thrive, they leave behind residues that nurture the soil. Sustainability lies in maintaining this cycle, not breaking it.

The Way Forward – Practical Tips for Farmers

Every farmer wants higher yield and better income, but the path to success is not only about feeding the crop; it is about **nurturing the soil** that sustains agriculture for generations. The following practical steps can help farmers improve soil health, reduce fertilizer costs, and increase crop productivity.

1. Test Your Soil Before You Invest

- Start with a **soil test** before sowing.
- It tells you exactly how much nitrogen, phosphorus, potassium, and micronutrients are needed.

- This avoids overuse of fertilizers, saves money, and prevents soil degradation.

2. Balance Fertilizer Use – Don't Rely on One Nutrient

- Many farmers apply **urea in excess**, thinking it gives quick results. But too much nitrogen makes plants weak and reduces grain quality.
- Always apply fertilizers in the **recommended ratio (N:P:K)**.
- Use a combination of **macro (N, P, K)** and **micro (zinc, boron, sulfur, iron)** nutrients.
- Balanced use ensures healthy crop growth and long-term soil fertility.

3. Add Organic Matter Back to the Soil

- Soil is like a bank account – if you only withdraw and never deposit, it will be empty one day.
- Add **farmyard manure, compost, green manure (dhaincha, sunhemp), or vermicompost**.
- Incorporate **crop residues** instead of burning them. This improves soil structure, water retention, and microbial activity.
- Even adding **2–3 tons of compost per acre** can reduce chemical fertilizer requirement.

4. Use Biofertilizers and Soil-Friendly Inputs

- **Rhizobium for pulses**, **Azotobacter for cereals**, and **PSB (Phosphate Solubilizing Bacteria)** can supply nutrients naturally.
- **Trichoderma** and **Azospirillum** improve plant growth and protect against diseases.
- Biofertilizers are low-cost, eco-friendly, and increase soil biological activity.

5. Follow Crop Rotation and Diversification

- Growing the same crop every year drains the soil of the same nutrients.
- Rotate cereals (rice, wheat, maize) with pulses (chickpea, pigeon pea, cowpea) to improve soil fertility.
- Intercropping systems (soybean + maize, chickpea + linseed) provide higher income and better soil health.

6. Apply Fertilizers in the Right Way

- **Split nitrogen application** – apply urea in 2–3 splits instead of one-time broadcasting. This increases fertilizer-use efficiency.
- **Deep placement of urea briquettes or neem-coated urea** reduces losses and ensures steady supply of nitrogen.
- Use **fertilizer mixtures with organic inputs** (e.g., 75% RDF + FYM/compost).

Healthy soil is like a healthy mother – it feeds your crop year after year. By following these simple steps – testing soil, balancing fertilizers, adding organic matter, using biofertilizers, rotating crops, and applying inputs wisely – farmers can achieve both better yields today and sustainable farming tomorrow.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Underutilized Fruits: A Storehouse of Nutrients

H.R. Meena[1], T.S. Chaithra[1], Meenakshi Meena[2] and Kuldeep Kumar[1]

[1]ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Kota-324002, Rajasthan
[2]Rajasthan College of Agriculture, Department of Horticulture, MPUAT, Udaipur- 313001, Rajasthan

Taste every fruit of every tree in the garden at least once. It is an insult to creation not to experience fully said famous British actor Stephen Fry. Tropical countries like India are blessed with a variety of fruits and vegetables that they naturally grow and produce. Fruits like mango, apples, banana, guava, citrus fruits, are available in plenty due to their distinct flavour and taste. These fruits also constantly enjoy the attention of organic scientists and horticulturists and are further improved in their quality. However fruits lovers and the common man should also remember that there are other fruits too that are sometimes termed as "underutilized fruits" that are hundred times more nutritious than the popular fruits in terms of their vitamin C, carotenoids and antioxidants. And added to this they are inexpensive and are easily available. Some of these too have a distinct flavour and taste and these are easy to grow even under harsh conditions as compared to exotic fruits like apples, mangoes, kiwis, cherries, grapes and their hybrids.

The underutilized fruit plants are also naturally disease tolerant and are adapted to hot, hardy climate conditions very much in sync with equatorial climate conditions. In India they are found locally in the dry region of Rajasthan, Madhya Pradesh and Gujarat. Some of them are confined to natural wild and semi-wild arid zones. Although the nutritional value of majority of the forest foods is not precisely known, but most of them which have been researched have been found to be a storehouse of nourishment.

Benefits of underutilized fruits

- They are cheap and highly nutritious.
- They have known medicinal and therapeutic properties and are used by the local people to cure various diseases.
- Many of them, the fruit, seed, leaf of the plant are used as curative foods in the traditional Indian Medicine and Ayurveda. For example, amla is used for treating diabetes, bael fruit for beating the heat, bael leaf for diabetes, and ber and phalsa being highly rich in vitamin C are used in cases of vitamin C deficiency.
- In addition some have an excellent flavor and taste and are used for preparing delicacies at home. eg. Ber, matira, pickles made of lasoda, or dishes made with ker, sangri, kachri, and kumat in Rajasthan.

Nutritive value of some underutilized fruits (per 100 g)

Underutilized Fruits	Protein (g)	Fibre (g)	Calcium (mg)	Phosphorous (mg)	Iron (mg)	Vitamin A (IU)	Vitamin C (mg)
Ker (*Capparis deciduas*) Shrub; fresh dried tiny unripe fruits used as vegetable and pickle, fresh red fruits eaten raw	5.9	12.3	153.8	50.8	2	-	133
Lasora (*Cordia myxa*) Fruit used as a veg **or** in pickles, ripe fruits freshly eaten	2	2	55	275	6	-	-
Sangri (*Prosopis cineraria*) Pods are locally called sangria; chocolate colour, dried pods are eaten as a vegetable	23.2	20	414	400	19		523
Meetha Pilu (*Salvadora oleoides*)	6	2	6	76	8	-	-

ISSN : 3048 - 989X

Fruits are red brown when ripe; eaten raw when ripe; can be cooked; dried and stored							
Bael (*Aegle marmelos*) Fruit are small to large with a hard cover; pulp eaten or made in a fresh sherbet, bael leaves good for diabetics	1.8	2.9	85	31.8	0.6	91.6	1.1
Chironji (*Buchanania lanzan*) Fruit eaten raw; sweetish sub acidic flavor	7.3	5.2	-	-	-	-	2
Karonda (*Carissa carandus*) Immature fruits used as vegetable, mature fruits eaten raw. Fruits are processed as pickle, jam, marmalade, chutney	1.1	1.8	21	28	-	1619	9-11
Aonla, Amla (*Emblica officinalis*) Fruit eaten fresh, processed and preserved	0.5	1.9 - 3.4	20	26	0.48	17	500-625
Phalsa (*Grewia subinaequalis*) Small tiny brown fruits; used to prepare a sherbet	1.3	1.2	129	39	3.1	800	22
Mahua (*Mahua indica*) Ripe fruits eaten raw or cooked	1.3	-	45	22	1.1	512	40.5
Khirni (*Manilkara hexandra*) Fresh fruits are very sweet and eaten raw as well as after drying	0.48	-	83	17	0.92	675	15.67
Manila tamarind (*Pithecellobium dulce*) Pulp consumed raw	2-3.3	1.1	13	42	0.5	25	138
Jamun (*Syzygium cumini*) Eaten as a fresh fruit Jamun seeds contain various alkaloids such as jambosin and glycoside which inhibits the conversion of starch in to sugars	0.7	0.9	15	15	1.2-1.6	80	18
Tamarind (*Tamarindus indica*) Eaten as a dried fruit and fruit pulp	2	2.9	34-94	34-78	0.2-0.9	-	44
Ber (***Zizyphus mauritiana***) Eaten as a fresh fruit	2	2	60	120	7	-	88
Hingota (*Balanites aegyptiaca*) Ripe fruits eaten raw or sun dried and stored as dates	4.9	3.5	147	58	4	-	46
Common Fruits							
Apple	0.2	1	10	14	1	-	1
Banana	1.2	0.4	17	36	0.9	78	7
Orange	0.7	0.3	26	20	0.3	1104	30
Papaya	0.6	0.8	17	13	0.5	666	57
Grapes	0.5	2.9	20	30	0.5	-	1
Mango	0.6	0.7	14	16	1.3	2743	16
Dates (dried)	2.5	3.9	120	50	7.3	26	3

Value added products of wild & underutilized fruits

Processed Product	Fruits
Candy	Aonla, Karonda, Tamarind
Glazed fruits	Tamarind, Annanas, Aonla
Confectionary	Amra, Aonla, Tamarind
Juice/Syrup/ Beverage / Squash	Aonla, Ber, Bael, Jamun, Karonda, Phalsa, Mulberry, Pomegranate
Wine	Mahua, Jujube, Ber, Indian fig, Karonda, Pomegranate
Chutney	Karonda, Woodapple, Aonla, Tamarind
Sauce	Karonda, Tamarind, Woodapple, Pomegranate, Tamarind
Pickle	Jujube, Tamarind, Ker ,Lasora, Gonda, Tamarind
Dehydration	Aonla, Karonda, Ker, Bael, Ber, Custard apple,
Frozen Puree	Bael, Karonda, Ker, Phalsa Tamarind, Custard apple
Canning	Ber, Aonla, Jamun, Ker
Burfi	Ber
Oil	Mahua, Ker, Aonla,
Processed Product	Fruits
Jam	Jamun, Karonda, Aonla, Mulberry, Soursop, Tamarind, Wood apple, Pomegranate
Jelly	Tamarind, Jamun, Karonda, Tamarind
Preserved	Ber, Aonla, Ker, Sangri, Karonda, Bael , Karonda, Soursop
Toffee	Custard apple, Ber, Bael, Tamarind
Powder/Churan	Ber, Aonla, Tamarind
Cereal bar	Beal
Anar Rub	Pomegranate
Anardana	Pomegranate
RTS	Tamarind
Concentrate	Tamarind
Granadine	Pomegranate
Hazmahazam	Pomegranate

Reasons for the under consumption of underutilized fruits

- Most indigenous fruit trees are not commonly cultivated on the farm and there is scant and dispersed knowledge about their fruits and their nutritive value.
- People prefer to have fruits with good taste since wild fruits have high levels of the unpleasant tasting tannins and glycosides.
- Indigenous fruits are neither large nor fleshy and contain lots of seeds.
- The fruits are highly perishable and difficult to store in the fresh form.
- Most wild fruits are not really easy and handy to eat.
- Some fruit species are not acceptable as fresh fruit because of high acidity and/or strong astringent taste.
- Most of them are often available only in the local markets and are rarely known in other parts of the country.

Strategies for Promotion of underutilized fruits

- **Research and Development**: Focus on developing improved varieties, pest-resistant strains, and better cultivation techniques.
- **Value Addition and Processing**: Establish small-scale processing units for jams, juices, powders, and medicinal products.
- **Awareness Campaigns**: Educate farmers and consumers about nutritional and economic benefits.
- **Inclusion in Government Schemes**: Integrate these crops into nutrition missions, horticulture development programs, and agroforestry initiatives.

- **Market Linkages**: Facilitate farmer-producer organizations (FPOs) and cooperative models to improve market access.

Conclusion

Underutilized fruit crops may be small in scale, but they hold **major value** in terms of nutrition, health, sustainability, and livelihood opportunities. Their resilience, cultural significance, and adaptability make them indispensable to local communities. By recognizing and promoting these hidden gems, we can diversify our food systems, empower rural economies, and build a healthier and more sustainable future.

Ker (*Capparis decidua*)

Karonda (*Carissa carandas*)

Mahua (*Madhuca indica*)

Khirni (*Menilkara hexendra*)

Jamun (*Syzygium cumini*)

Tamarind (*Tamarindus indica*)

Sangri (*Prosopis cineraria*)

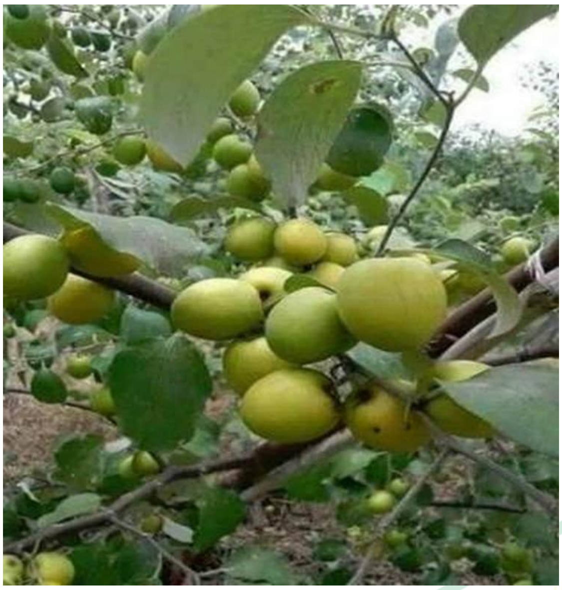
Amra (*Spondias mombin*)

Wood apple (*Limonia acidissima*)

Sour sop (*Annona muricata*)

Pilu (*Salvadora persica*)

Bael (*Aegle marmelos*)



Ber (*Ziziphus mauritiana*)

Phalsa (*Grewia asiatica*)

Chironji (*Buchanania lanzan*)

Jharber (*Ziziphus numularia*)

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Enrichment, Value Addition, and Densification of Maize Straw: Sustainable Approaches for Agricultural Residue Utilization

[1]Dr. Simranjeet Kaur, [1]Dr. Harsimran Kaur, [2]Dr. Harinder Singh
[1]Ph.D., School of Business Studies, Punjab Agricultural University
[2]M.Sc. Animal Nutrition, Excellent Enterprises, Khanna

Abstract
Maize straw, a significant agricultural residue, holds immense potential for enrichment, value addition, and densification to enhance its utility in various applications. This article explores the processes and technologies involved in transforming maize straw into valuable products, including bioenergy, animal feed, and soil amendments. Enrichment through nutrient enhancement, value addition via product diversification, and densification for efficient handling, store and transport are discussed, supported by recent research. The article also highlights the environmental and economic benefits of these processes, emphasizing sustainable agricultural practices, including dry fodder security to World's largest cattle population.

1. Introduction
Maize (*Zea mays* L.) is a major global cereal crop, contributing significantly to food security and agricultural economies. However, its cultivation generates substantial residues, primarily maize straw (stover), which constitutes 47–50% of the plant's dry mass (Saritha et al., 2020). Traditionally, maize straw is either burned, causing environmental pollution, or left in fields, leading to inefficient resource use. Enrichment, value addition, and densification offer sustainable pathways to utilize maize straw, enhancing its nutritional, industrial, and energy applications while mitigating environmental impacts. This article examines these processes, their benefits, and challenges, with a focus on sustainable agricultural residue management. Recent technological advancements & development of ethanol from maize will add extra straw volumes, good to explore business in straw's commercial processing for dairy animals.

2. Enrichment of Maize Straw
Enrichment of maize straw involves enhancing its nutritional or functional properties to improve its utility, particularly as animal feed or soil amendments.

2.1 Nutritional Enrichment for Animal Feed
Maize straw is often low in digestible nutrients, limiting its use as livestock fodder. Enrichment techniques, such as microbial fermentation or biological treatment, can improve its nutritional quality. For instance, adding forage rape (Brassica napus L.) during silage fermentation reduces the Shannon and Chao1 indices, indicating a shift in microbial communities that enhances silage quality by inhibiting undesirable bacteria (Li et al., 2023). This process increases the digestibility and protein content of maize straw, making it a viable feed option.

2.2 Soil Fertility Enhancement
Incorporating maize straw into soil, combined with phosphorus (P) or nitrogen (N) fertilizers, enhances soil organic carbon (SOC) and nutrient availability. Studies show that straw return with P application increases maize growth by improving soil carbon and phosphorus fractions, with a 15.36% increase in dry matter weight under high P treatments (Guo et al., 2024). Additionally, straw incorporation boosts soil microbial biomass carbon (SMBC), urease and other enzyme activities, promoting soil fertility and crop productivity (Yang et al., 2024).

3. Value Addition of Maize Straw
Value addition transforms maize straw into diverse products, expanding its applications beyond traditional uses.

3.1 Bioenergy Production
Maize straw's lignocellulosic components (cellulose, hemicellulose and lignin) make it a promising feedstock for bioenergy. Densification into pellets or briquettes enhances its energy density, facilitating bioethanol or biogas production. Research indicates that densification variables, such as biomass type and pretreatment methods, significantly impact the quality of biofuels produced (World Scientific, 2023).

3.2 Industrial Products

Maize straw can be processed into value-added industrial products, such as bioplastics, specialty chemicals, and composite materials. For instance, scientists in Japan have developed a biodegradable plastic from maize straw-derived additives that decomposes in seawater and soil, releasing nutrients without leaving microplastics (Rainmaker1973, 2025). Such innovations highlight the potential for maize straw in sustainable material production.

3.3 Animal Feed and Nutritional Products

Value-added products like silage, fortified feed, and fermented products enhance maize straw's role in livestock nutrition. Combining maize straw with legumes or other nutrient-rich additives improves protein quality, as seen in products like QPM (Quality Protein Maize) blends with soya bean or green gram (Yadav & Supriya, 2013).

4. Densification of Maize Straw

Densification involves compacting maize straw into pellets, briquettes, or other forms to improve its handling, storage, and transport efficiency.

4.1 Techniques and Benefits

Densification techniques, such as pelleting or briquetting, reduce the volume of maize straw, lowering transportation costs and improving combustion efficiency for bioenergy applications. Deep incorporation of densified straw (e.g., at 30 cm depth) enhances soil water storage and nutrient availability, leading to a 16.1–19.7% increase in maize yield compared to shallow incorporation (Huai et al., 2024). Densified straw also facilitates efficient use in biogas digesters and biofuel production systems.

4.2 Challenges in Densification

The densification process requires energy-intensive equipment and optimized conditions (e.g., moisture content, particle size) to produce high-quality pellets. The choice of pretreatment methods, such as thermal or chemical processing, significantly affects the energy efficiency and environmental footprint of densified products (World Scientific, 2023).

5. Environmental and Economic Benefits

Enrichment, value addition, and densification of maize straw offer multiple benefits:

- **Environmental Sustainability**: Straw incorporation reduces greenhouse gas emissions from burning and enhances SOC, mitigating climate change (Guo et al., 2024).
- **Economic Viability**: Value-added products like biofuels and bioplastics create new revenue streams for farmers, while densification reduces logistics costs (Huai et al., 2024).
- **Agricultural Productivity**: Nutrient-enriched straw improves soil fertility and crop yields, supporting food security (Yang et al., 2024).

6. Challenges and Future Directions

Despite its potential, challenges include high processing costs, limited awareness among farmers, and the need for region-specific technologies. Future research should focus on cost-effective densification methods, scalable enrichment techniques, and policy incentives to promote straw utilization. Integrating advanced technologies like laser-induced breakdown spectroscopy with machine learning for soil property analysis could further optimize straw management (ArewaFactsZone, 2025).

7. Conclusion

Enrichment, value addition, and densification of maize straw transform agricultural residues into valuable resources, supporting sustainable agriculture and circular economies. By enhancing nutritional quality, diversifying product applications, and improving handling efficiency, these processes address environmental and economic challenges. Continued research and policy support are essential to unlock the full potential of maize straw utilization.

References

ArewaFactsZone. (2025, July 31). Big congratulations to @yakubwudil for securing a U.S. patent. Retrieved from https://t.co/jpI5gCDRwX

Guo, Z., Ye, W., Wang, H., He, W., Tian, Y., Hu, G., Lou, Y., Pan, H., Yang, Q., & Zhuge, Y. (2024). Straw and phosphorus applications promote maize (Zea mays L.) growth in saline soil through changing soil carbon and phosphorus fractions. *Frontiers in Plant Science*, *15*, 1336300.

Huai, S., Wang, S., Yu, W., Zhang, Q., Wu, H., Xing, T., Jin, Y., Colinet, G., & Lu, C. (2024). Short-term effects of incorporation depth of straw combined with manure during the fallow season on maize production, water efficiency, and nutrient utilization in rainfed regions. *Agronomy*, *14*(11), 2504.

Li, Y., Li, Y., Zhang, H., Wang, L., Wang, W., Wang, Z., ... & Zhang, M. (2023). Effect of maize straw additives on the nutritional quality and bacterial community of *Brassica napus* L. silage. *Ciencia Rural*, *53*(4).

Rainmaker1973. (2025, August 4). Scientists in Japan made a plastic that dissolves in seawater. Retrieved from https://t.co/w22ZEdb4Rx

Saritha, M., Suseela, P., Rajani, V., & Reddy, A. V. (2020). Nutritional importance and value addition in maize. *Biotica Research Today*, *2*(9), 974–977.

World Scientific. (2023, July 1). This book explains how the densification process variables impact the quality of densified products for biofuel production. Retrieved from https://t.co/y8MuhLfSpd

Yadav, V. K., & Supriya, P. (201 new3). Value addition in maize. In *Maize: Nutrition Dynamics and Novel Uses* (pp. 141–152). Springer.

Yang, L., Chen, T. Y., Li, Z. Y., Muhammad, I., Chi, Y. X., & Zhou, X. B. (2024). Straw incorporation and nitrogen fertilization regulate soil quality, enzyme activities, and maize crop productivity in dual maize cropping system. *BMC Plant Biology*, *24*, 729.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Production Technologies for Sustainable Finger Millet Cultivation in Semi-Arid Regions

Dr. R. Naseeruddin[1], Dr. L. Madhavi Latha[2], and Dr. M. Vijay Sankar Babu[3]

[1]Scientist (Agro.), ARS, Ananthapuramu; [2]Principal Scientist (GPBR), ARS, Ananthapuramu; [3]Principal Scientist & Head, ARS, Ananthapuramu

Abstract

Finger millet (*Eleusine coracana* Gaertn.), commonly known as ragi, is one of the most important small millets grown in India, primarily for its grain and fodder value. Despite its nutritional superiority and climate resilience, the area under finger millet cultivation has declined in recent decades due to urbanization, labor-intensive processing, and limited modern technologies. However, with increasing awareness of millet-based nutrition and climate change challenges, finger millet is regaining importance as a sustainable food crop. This article reviews improved production technologies, including high-yielding varieties, soil and nutrient management, integrated pest and disease management, and advanced cultivation practices aimed at enhancing yield and productivity in Andhra Pradesh.

Introduction:

Finger millet is a premier small millet crop extensively cultivated across India, particularly in Karnataka, Tamil Nadu, Maharashtra, Andhra Pradesh, Odisha, Bihar, Himachal Pradesh, and Uttarakhand. It is predominantly grown in dry regions where it serves as a staple food and livestock feed. In Andhra Pradesh, finger millet occupies approximately 50,000 ha, producing 52,000 tonnes with an average productivity of 1,189 kg/ha. In the context of 21st-century agricultural challenges—climate change, water scarcity, population pressure, food price volatility, and nutritional insecurity—millets, especially finger millet, offer a promising solution. Given the shrinking cultivation area, boosting productivity through improved technologies is critical. This review summarizes state-specific production practices and high-yielding varieties recommended for Andhra Pradesh.

Agro-Climatic Requirements:

Finger millet thrives in tropical regions and can be cultivated year-round with proper moisture management. Optimal Rainfall: 600–800 mm (well-distributed)

Seasons:

- Kharif: June–July
- Rabi: September–October
- Summer: January–February

- **Soils:** Red sandy loam soils with good drainage; the crop is intolerant to waterlogging.

High-Yielding Varieties for Andhra Pradesh

Variety	Duration (days)	Yield (q/ha)	Key Features
Godavari (PR 202)	115–120	30–40	Drought and blast tolerant; adaptable across seasons
Ratnagiri (PR 1044)	110–115	30–40	Blast tolerant; multi-season suitability
Padmavati (PPR 2350)	100–105	28–40	Suitable for all ragi-growing regions
Saptagiri (PPR 2614)	100–105	25–40	Early planting; non-lodging; waterlogging and drought tolerance
Champavati (VR 708)	80–85	20–25	Drought tolerant; ideal for intercropping with pigeonpea
Maruthi (RR 230)	85–90	25–30	Early maturing; drought and blast tolerant
Bharathi (VR 862)	105–110	35–40	Blast tolerant; suitable for all seasons
Sri Chaitanya (VR 847)	105–110	35–45	Suitable for early/late Kharif and irrigated Rabi
Vakula (PPR 2700)	100–105	35–40	Leaf blast tolerant; semi-dwarf

Hima (VR (W) 936)	110–115	25–30	White grain; blast tolerant; Rabi season variety
Tirumala	115–120	35–40	Resistant to multiple blast types; high straw yield
Vegavathi	110–115	35–40	Lodging and leaf blast resistant
Suwarnamukhi	105–110	35–40	Blast tolerant; suitable for paddy fields and drought-prone areas
Gouthami	115–120	35–40	Leaf blast resistant; lodging resistant
Indravathi	115–120	35–40	Blast resistant; enriched with calcium, iron, and zinc

Land Preparation and Sowing

- **Primary Tillage:** One deep ploughing (mould board) followed by two wooden ploughings during summer.
- **Secondary Tillage:** Cultivator and multiple-tooth hoe to achieve fine tilth.
- **Seed Rate:**
  - Direct sowing: 8–10 kg/ha
  - Transplanting: 5–6 kg/ha
- **Seed Treatment:** Treat seeds with Thiram/Carbendazim/Mancozeb (2 g/kg seed) 24 hours before sowing.

Sowing Methods

- **Direct Sowing:**
  - Broadcasting (mixed with sand)
  - Line sowing using seed drill (spacing: 15–20 × 7.5–10 cm)
- **Transplanting:**
  - Nursery raised on 400 m² for 1 ha planting
  - 20–25-day-old seedlings transplanted at 22.5 × 10 cm spacing
  - Benefits: Uniform plant population, higher tillering, reduced lodging

Fertilizer Recommendations

Apply 5-6 tons of farm yard manure is required for one hectare field for enhancing soil health and crop productivity. The fertilizer requirement of ragi crop as follows.

Condition	**Fertilizer Dose (N:P:K kg/ha)**	**Application Method**
Rainfed	40:20:20	Basal P and K; N in 2 splits (basal + 25–30 DAS)
Irrigated	60:40:30	Basal P and K; N in 3 splits (basal + 25–30 DAS)

Weed Management

- **Manual:**
  - Broadcasting: 2 hand weedings
  - Line sowing: 2–3 intercultivations + 1 hand weeding
  - Transplanting: Single hand weeding at 21 DAT
- **Chemical:**
  - Pre-emergence: Pendimethalin @ 3 ml/L
  - Post-emergence: 2,4-D sodium salt @ 2 g/L (20–25 DAP)

Water Management

- Rainfed crops rely on natural moisture but require adequate soil moisture at germination, tillering, flowering, and grain filling.
- Irrigated fields should be prepared with ridges and furrows; irrigation interval:
  - 7–8 days (light soils)
  - 13–15 days (heavy soils)Mor Ins Pests and Diseases

Major Insect Pests and Diseases

Pest/Disease	Chemical Recommendation
Armyworms, Cutworms	Malathion 5% dust (20–25 kg/ha); Chlorpyriphos 2.5 ml/L
Leaf Aphids	Dimethoate 2 ml/L
Stem Borers	Dimethoate or Phosphamidon 2 ml/L
Ear Head Caterpillars	Malathion or Phosalone dust (20–25 kg/ha); Chlorpyriphos 2 ml/L
Blast Disease	Carbendazim 2 g/kg seed; Tricyclazole 0.5 g/L spray
Brown Leaf Spot	Mancozeb 2.5 g/L
Leaf Blight	Captan/Thiram 3 g/kg seed; Mancozeb 2.5 g/L

Harvesting:

When the grain colour turns to brown and becomes hard, harvesting can be done. The time of harvesting varies depending the duration of the varieties grown. In Ragi crop mother tiller matures first when compared to the side tillers, so depending upon the maturity 2-3 pickings are necessary for harvesting the entire produce.

Threshing and storage:

The harvested crop is stacked for about 1-2 days and dry the ear heads under sunlight before threshing. The threshed grain should be winnowed, cleaned and dried properly before storage. The grain is free from any serious pest damage during storage and it keeps well for several years provided it is kept dry. Dry straw can also be stored for long time and used as fodder.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Sustainable Agriculture for Climate Resilient Farming

Apsara K P[1], Aditya Arunkumar Bikkannavar[2], Rachana[3] and Syed Abdul Khadar Quadri Jeelani[4]

Ph. D. Scholar (Department of Agricultural Economics)[1]
Ph. D. Scholar (Department of Resource Management and Consumer Science)[2]
Ph.D. Scholar Department of Forest Resource Management, CoF, UAS, Dharwad[3]
PGDM (Agri Business Management), MANAGE, Hyderabad[4]

1. Introduction

Climate change poses significant challenges to global agriculture through increased frequency of extreme weather, temperature variability, and unpredictable precipitation. For economies heavily dependent on agriculture like India these challenges threaten food security, farmer livelihoods, and rural economies. Climate-resilient agriculture (CRA) offers a comprehensive framework to address this crisis by integrating **sustainable practices** such as conservation agriculture, agroforestry, integrated farming systems, and climate-smart technologies. These practices collectively enhance the ability of agricultural systems to **adapt**, **mitigate**, and remain **economically viable**, thereby transforming agriculture into a key tool for climate resilience and sustainable development.

2. Foundations of Climate-Resilient Agriculture

2.1. Defining Climate-resilient agriculture

CRA refers to farming strategies that boost the ability of agricultural systems to absorb climatic shocks while maintaining productivity and providing environmental and socioeconomic co-benefits. A recent literature review defines CRA as practices adapted to local hydro-meteorological conditions, aimed at enhancing water exchange and ensuring agricultural viability in water-scarce regions like India (Sahoo and Singha, 2024).

2.2. The Imperative in India

CRA is particularly vital for India, where over 60% of farmland relies on rainfed systems, making it susceptible to erratic rainfall and droughts . Between 2010–2023, Punjab alone recorded 128 heatwave days, causing significant declines in wheat yield and exacerbating air pollution (times of india, 2025). This has triggered calls—such as from FAIFA—for urgent CRA adoption, especially for smallholder farmers.

3. Key Sustainable Agriculture Practices

3.1. Conservation Agriculture: No-Till & Cover Crops

Conservation agriculture—characterized by minimal soil disturbance through no-till practices, continuous soil cover, and systematic crop rotation—substantially enhances climate resilience by improving soil organic carbon (SOC), increasing water infiltration, and retaining soil moisture. Meta-analyses from China indicate that long-term no-till significantly decreases methane emissions and can reduce nitrous oxide (N_2O) emissions under alkaline soils, extended duration, and lower nitrogen inputs (Zhao *et al.*, 2016). Complementary use of cover crops with reduced tillage further boosts carbon sequestration, increasing SOC stocks by 15–25% within a decade (Amin *et al.*, 2025). In a real-world application from Bihar, integration of climate-resilient agriculture practices—including conservation tillage and cover crops—raised the wheat benefit–cost ratio from 1.8 to 2.23, demonstrating higher yields and reduced input costs.

3.2. Agroforestry & Silvo-pasture

Agroforestry systems—integrating trees with crops and/or livestock—significantly bolster soil health and farm resilience. A meta-analysis in humid and sub-humid tropics found that agroforestry reduced soil erosion by roughly 50%, increased soil organic carbon and nitrogen storage, and improved phosphorus levels compared to monocultures. Trees contribute nutrient-rich organic matter through litter and root decay, enhancing soil structure, water infiltration, and fertility—evidenced in Bali where agroforestry markedly improved these parameters (Muchane, 2020).

Silvopasture, a form of agroforestry combining trees with grazing livestock, offers strong climate mitigation benefits. Research shows that mixed systems sequester more carbon than open pastures, reduce nitrous oxide emissions, and diversify farm income through timber, forage, and animal products . For instance, silvopastures function as carbon sinks, improve soil carbon retention, buffer microclimates, and generate multiple revenue streams—a sustainable, resilient model for modern agriculture (Delon, 2024).

3.3. Crop Diversification & Integrated Farming Systems (IFS)

- **Diversification** through intercropping or rotations reduces yield risk and boosts biodiversity and profitability. A meta-analysis over 50 years shows ecosystem services rising up to 2,823% with diversification (Raveloaritiana, 2024).
- **IFS** blends cropping with aquaculture, livestock, and agroforestry to create resilient farm ecosystems. A Cambodian study noted significant improvements in resilience and income through participatory IFS planning.

3.4. Water-Efficient Irrigation & Rainwater Harvesting

Water-Efficient Irrigation and Rainwater Harvesting are key pillars of climate-resilient agriculture (CRA), especially in regions facing water scarcity. Techniques such as drip irrigation, rainwater storage structures, and micro-irrigation ponds enable precise and efficient use of available water resources. These practices not only reduce water wastage but also improve crop yield and water productivity. In northwestern India, where groundwater is being depleted at an alarming rate of approximately 7.4 cm per year, such interventions have become essential to ensure the sustainability of agriculture. A review by the International Center for Agricultural Research in the Dry Areas (ICARDA) emphasizes that climate-resilient water management—especially in semi-arid and arid zones—must integrate these low-cost, efficient irrigation technologies to improve resilience and long-term agricultural viability (Sahoo and Singha *et al.*, 2024).

3.5. Climate-Smart Seeds & Crop Varieties

Climate-Resilient Crop Varieties and Innovative Cultivation Techniques play a vital role in adapting agriculture to changing climatic conditions. The development and wide-scale deployment of drought-tolerant, heat-resistant, and early-maturing crop varieties are essential to ensure food security in the face of temperature extremes, erratic rainfall, and shorter growing seasons. India has made notable progress in this direction by releasing **109 climate-resilient crop varieties**, reflecting strong policy backing for agricultural adaptation and innovation (**Arasu,** 2024).

In addition, the **System of Rice Intensification (SRI)** and **direct-seeded rice (DSR)** techniques have emerged as effective solutions to conserve water and reduce greenhouse gas emissions. These methods, particularly adopted in Odisha and similar states, not only enhance water use efficiency but also lower methane emissions typically associated with flooded paddy fields. According to a report by the Council on Energy, Environment and Water (CEEW), scaling these methods can significantly improve yields while reducing input costs and environmental footprints, making them critical components of climate-resilient agriculture in India (**Shukla, 2025)**.

3.6. Precision and AI-Driven Agriculture

Precision and AI-Driven Agriculture is revolutionizing the way farmers manage resources, monitor crops, and respond to climate variability. Technologies such as satellite imaging, the Internet of Things (IoT), field sensors, and Artificial Intelligence (AI) are enabling more accurate weather forecasting, soil analysis, pest detection, and input application. These tools help farmers make data-driven decisions, improving efficiency and resilience. A recent advancement is the **AI-powered "Soil Carbon Copilot"**, which uses real-time weather data and field management records to estimate soil carbon sequestration potential, supporting the transition to **regenerative agriculture** and climate-smart farming systems (Ruth et al., 2024).

Indigenous and Traditional Knowledge Systems also play a critical role in building climate-resilient agriculture. Indigenous communities across India have long practiced sustainable farming methods such as **agroforestry, mixed cropping, and traditional water harvesting** suited to local conditions. These time-tested practices not only enhance soil fertility and crop diversity but also buffer against climatic stress. A study highlights how recognizing and integrating such knowledge strengthens the cultural and ecological foundation of CRA, making adaptation strategies more inclusive and effective (Sujitha *et al.*, 2024).

4. Benefits of CRA

4.1. Environmental Gains

- **Carbon Sequestration**: Conservation tillage, agroforestry, and silvopasture trap CO_2 in soils and biomass.
- **Water Management**: Improved infiltration and storage reduce drought risk.
- **Biodiversity**: Crop and species diversity support ecosystems and resilience.

4.2. Economic & Social Advantages

- **Stability & Profit:** Diversified systems mitigate risks while improving profitability.
- **Livelihood Security:** Multi-enterprise systems (crops, livestock, trees, fish) reduce dependence on weather or markets.
- **Inclusivity:** Community-based structures and indigenous methods build local knowledge and gender equity.

5. Barriers to CRA Adoption

5.1. Institutional and Policy Hurdles

- Inconsistent subsidy systems and weak extension models limit adoption.
- Scaling of digital and AI tools is impeded by infrastructure, awareness, and training gaps.

5.2. Technical and Knowledge Barriers

- Transitioning to new seed varieties and techniques requires farm-level understanding and investment.
- Effective no-till adoption relies on local soil knowledge and mechanisms to ensure long-term benefits.

5.3. Financial Constraints

- Upfront costs for micro-irrigation, agroforestry, and AI solutions remain high. Access to green finance and carbon credits is limited.

6. Policy & Institutional Directions

6.1. Strengthening Extension Systems

- Enhance decentralized, climate-smart advisory through Krishi Vigyan Kendras (KVKs), cooperatives, and ICT-enabled platforms.

6.2. Incentive Reforms

- Redirect subsidies to reward eco-friendly practices (e.g., carbon payments, micro-irrigation), similar to the UK's Environmental Land Management schemes.
- Scale NICRA modules and Odisha's thematic approaches to build systemic coordination.

6.3. Financial Innovation & Private Partnerships

- Promote private funding, impact investment, and carbon finance pathways (e.g., regenerative carbon credits) to support resource-limited farmers.
- Encourage partnerships with agro-tech firms and agribusinesses for scalable interventions.

6.4. Research, Tech, and Metrics

- Invest in AI, sensors, crop breeding, and performance evaluation metrics.
- Develop sustainability indicators for carbon, water, biodiversity, and socioeconomic outcomes.

6.5. Local Engagement & Social Inclusion

- Empower women and indigenous communities by integrating their knowledge in CRA planning.
- Strengthen farmer cooperatives, extension networks, and digital communities for farmer-led innovation.

CRA aligns with global goals: COP30 discussions center on food systems, and the World Bank promotes transformative investments in agriculture—emphasizing agroforestry, diet changes, and subsidy realignment. Estimates suggest agriculture could absorb $260 billion/year in climate financing—worth 16× in co-benefits (jobs, health, biodiversity, food security) by 2030.

India is strategically positioned to lead in CRA adoption: with ongoing programs (NICRA, NMSA), agritech advances, and growing recognition of indigenous practices, a coordinated national push can multiply resilience and impact.

7. Conclusion

Climate-resilient agriculture provides a **scientifically grounded, socio-economically robust, and ecologically beneficial** path forward. By embracing diversified cropping, agroforestry, conservation tillage, water-smart practices, and climate-resistant seeds, CRA builds an adaptive buffer against climate uncertainty. However, its potential hinges on systemic support—through enabling policy, finance, research, institution-strengthening, and equitable farmer participation.

As climate challenges escalate, CRA must shift from pilot to norm. Implementing inclusive, locally adapted, and financially viable CRA strategies will not only secure farmer incomes and food systems, but also deliver on national sustainability ambitions, rural development, and rural climate action goals. It's a transformative vision that calls for urgent action—and offers a sustainable future.

References

Amin, R., Jan, S.S., Butt, M., Manan, A., Khan, M., Khan, R.A., Sadiq, A.B. and Ali, S., 2025. SOIL CARBON SEQUESTRATION THROUGH COVER CROPS AND REDUCED TILLAGE: A CLIMATE-SMART AGRICULTURAL STRATEGY FOR MITIGATING CLIMATE CHANGE AND IMPROVING SOIL HEALTH. *Kashf Journal of Multidisciplinary Research*, *2*(04), pp.20-37.

Arasu, S, 2024, *In India, warming climate pressures scientists to keep developing tougher seeds*

Delon, C., Grippa, M., Mougin, E., Ngom, D., Gaglo, K.E., Ndiaye, O., Salgado, P. and Roupsard, O., 2024. Modelling CO2 and N2O emissions from soils in silvopastoral systems of the West-African Sahelian band.

FAIFA's climate resilience appeal (June 2025) (timesofindia.indiatimes.com).

Muchane, M.N., Sileshi, G.W., Gripenberg, S., Jonsson, M., Pumariño, L. and Barrios, E., 2020. Agroforestry boosts soil health in the humid and sub-humid tropics: A meta-analysis. *Agriculture, Ecosystems & Environment*, *295*, p.106899.

Raveloaritiana, E. and Wanger, T.C., 2024. Decades matter: Agricultural diversification increases financial profitability, biodiversity, and ecosystem services over time. *arXiv preprint arXiv:2403.05599*.

Sahoo, S., and Singha, C., 2024, *Review of climate-resilient agriculture for ensuring food security: Sustainability opportunities and challenges of India*. Environmental and Sustainability Indicators, 25.

Shukla, Shashwat; Sijo Abraham; and Saahil Parekh , 2025, *Advancing Climate-resilient Agriculture in India by Strengthening Institutional Capacity: Lessons from Bihar and Odisha.* New Delhi: Council on Energy, Environment and Water.

Zhao X, Liu SL, Pu C, Zhang XQ, Xue JF, Zhang R, Wang YQ, Lal R, Zhang HL, Chen F. 2016. Methane and nitrous oxide emissions under no-till farming in China: a meta-analysis. Glob Chang Biol. ;22(4):1372-84. doi: 10.1111/gcb.13185. Epub 2016 Feb 9. PMID: 26661415.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Farming Without Soil: The Rise of Hydroponics and Aeroponics

Devasena P

PG Scholar, Department of vegetable science,
Horticultural College and Research Institue, TNAU, Periyakulam, Theni

ABSTRACT

Traditional farming methods are facing unprecedented challenges, including soil degradation, water scarcity, and climate change. In response, innovative farming techniques such as hydroponics and aeroponics have emerged as viable alternatives. Hydroponics, a method of growing plants in a liquid nutrient solution, has been gaining popularity since its introduction in the 1920s. By eliminating the need for soil, hydroponics and aeroponics offer numerous benefits, including increased crop yields, reduced water consumption, and year-round production. From tomatoes and cucumbers to herbs and ornamental crops, we examine the diverse range of crops that can be grown using hydroponics and aeroponics. As the global agriculture industry faces increasing pressure to meet the demands of a growing population, this highlights the potential of soilless farming to revolutionize the way we produce food, ensuring a sustainable and food-secure future.

KEYWORDS: Hydroponics, aeroponics, reduced water consumption, nutrient solution, increased food production.

INTRODUCTION

Hydroponics is the process of growing plants in a liquid nutrient solution, with or without the use of artificial medium. Expanded clay, coir, and perlite are often used as medium. Materials used are vermiculite, brick shards, polystyrene packing peanuts, and wood fiber. Hydroponics is an effective way to grow vegetables like tomatoes, lettuce, cucumbers, and peppers, as well as ornamental crops like herbs, roses, and foliage plants. The word hydroponics comes from two Greek words 'hydro' meaning water and 'ponos' meaning labor. This word was first used in 1929 by Dr. Gericke, a California professor who began to develop what previously had been a laboratory technique into a commercial means of growing plants. The U.S. Army used hydroponic culture to grow fresh food for troops stationed on infertile Pacific islands during World War II. By the 1950s, there were viable commercial farms in America, Europe, Africa and Asia.

Aeroponic comes from the Latin words 'aero' (air) and 'ponic' (labor or work). Aeroponics is the soilless cultivation and it is a process of growing crops suspended in the air or in a mist without using soil. The principles of aeroponics are based on the possibility of cultivating whose roots are not inserted in a substratum or soil, but in containers filled with flowing plant nutrition. In these containers' roots can find the best condition regarding oxygenation and moisture. In the early 1921s, Barker first developed primitive air plant growing system and used for laboratory work to investigate the plant root structure. He reported that air plant growing technique is the natural and simple practice to grow plants without incorporation of soil. The absence of soil made study much easier.

TYPES OF HYDROPONICS

1. **DEEPWATER CULTURE (DWC):** In deep water culture, plant roots are suspended in nutrient-rich water, and an air stone delivers air straight to the roots. A classic example of this technique is the hydroponic bucket system. In net pots, where their roots are suspended in a nutritional solution, plants rapidly grow into huge masses. Since algae and molds can grow quickly in the reservoir, it is imperative to keep an eye on the oxygen and nutrient concentrations, pH, and salinity. This technique is highly effective for larger fruit-bearing plants, particularly tomatoes and cucumbers.
2. **DRIP SYSTEM**: In this technique, the plants are grown independently in a soilless media while the nutrient solution is kept apart in a reservoir. With the aid of a pump, each plant root receives the proper amount of water or nutrients solution from the reservoir. Through nozzles, drip systems slowly dispense nutrients. The

excess solutions can be gathered and recycled or simply let leak out. It is achievable to cultivate multiple plant species at the same time with this technique.

3. **EBB AND FLOW**: This is the first commercial hydroponic system that uses the flood-drain mechanism. A grow tray and a reservoir with a nutritional solution within are used in this setup. The fertilizer solution is periodically flooded into the grow tray by a pump and then gradually drained away. Though it is feasible to cultivate a variety of crops, a customized system with a filtration unit is necessary because root rot, algae, and mold are common problems.
4. **NUTRIENT FILM TECHNIQUE (NFT)**: Dr. Alen Cooper created NFT in England in the middle of the 1960s to address the drawbacks of the ebb and flow system. The most often used hydroponic system is the nutrient film technique (NFT), which is similar to aeroponics. This technique involves continuously pumping a nutritional solution via ducts that hold plants. The nutrient solutions are returned to the starting point of the system when they reach the end of the channel. It is therefore a recirculating system; however, in contrast to DWC, the roots of the plants are not entirely immersed.
5. **WICK SYSTEM**: This is a basic hydroponic system; it requires neither an aerator, pump, or electricity. With a nylon wick extending from the roots of the plants into a reservoir of nutrient solution, the plants are set in an absorbent media such as coco coir, vermiculite, or perlite. Through capillary action, plants get water or nutritional solutions. This technique is effective for herbs, spices, and tiny plants.
6. **AEROPONICS**: The most advanced form of hydroponic gardening is possibly the Aeroponic System. Like other hydroponic systems, the nutrient pump is controlled by a timer. However, the aeroponic system requires a brief cycle timer that operates the pump for a few seconds every couple of minutes, usually during which the nutrient is sprayed.

MISTING FREQUENCY IN AEROPONICS

In the aeroponics system, the atomization spray time and interval time are the essential factors for successful plant cultivation. The aeroponics system is performed without soil. Therefore, it is essential for the grower to fix the atomization spray time and interval time based on the plant requirement. The wrong schedule could create serious problems for plant growth because in the system there is no any medium to support the plant. Many research studies had been successfully cultivated plant under different atomization spray time and interval time.

However, the potato had been cultivated under the atomization spray time and interval time 20-sec on and 5-min off, 3min on and 5-min off, 3-sec on and 10-min off, 30-sec on and 5-min off, 10-sec on and 20-mint off, 15-min on and 15-min off during day time and 15-min on and 1-h off during night time. The successfully cultivation of tomato under the atomization spray time and interval time of 3-sec on and 10-min off, and 60-sec on and 5-min off respectively. Moreover, many studies cultivated several plants under different atomization spray time and interval time such as cucumber 7-sec on and 10-min off, lettuce1.5-min on and 5-min off, Saffron 1-min on and 1-min off, Maize 1-sec on and 15-mints off, Peas (Pisum sativum) 3-sec on and 10-mins off, Onion 7-sec on and 90-sec off. In the aeroponics system, the nutrient reservoir is designated as separate or outside and inside or within the growth chamber.

PERECENTAGE OF HYDROGEN (pH)

An important chemical property of a nutrient solution is its pH, a scale of 1 to 14 used to specify acidity or alkalinity of a solution. At room temperature, water is neither basic nor acidic, hence it has been assigned a pH of 7. Solutions with pH higher than 7 are basic, and acidic otherwise. Most authors agree that the nutrient solution must have pH between 5 and 7, since it is in such interval that nutrients remain soluble. However, if pH > 7, the solubility of Fe and H2PO4 decreases, giving rise to Ca and Mg precipitates, among other chemical reactions between nutrient solution components, hindering the absorption of iron, boron, copper, zinc, or manganese. On the other hand, if pH is below 5, the adsorption of nitrogen, phosphorus, potassium, calcium, magnesium, and molybdenum is inhibited.

ELECTRICAL CONDUCTIVITY (EC)

EC, is an estimation of the total concentration of ions in a solution. In this case low values of EC indicate a scarcity of nutrients in the form of ions; on the other hand, too-high values may lead to salt stress in the plant. Thus, EC should be kept within a target range because it significantly affects growth and crop quality. Additionally, this parameter does not provide specific information regarding the concentration of each element in the nutrient solution; hence, after measuring EC, it is essential to add fertilizers in concentration amounts that the plants can absorb.

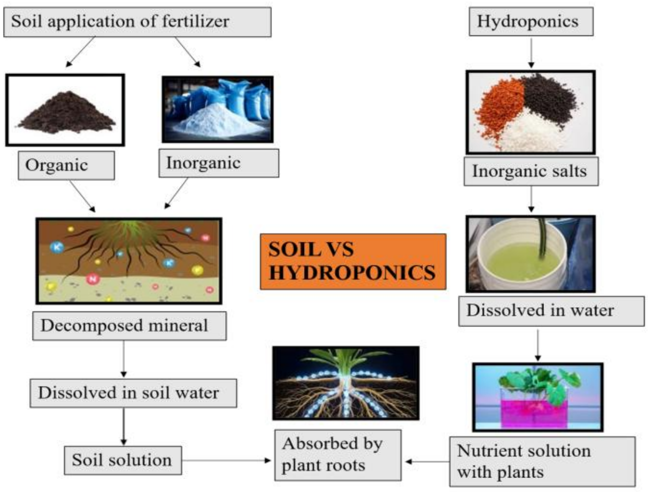
CROP	EC (dSm^{-1})	pH
Tomato	6.0 - 6.5	2.0 – 4.0
Pepper	5.5 - 6.0	0.8 – 1.8
Egg plant	6.0	2.5 - 3.5
Cucumber	5.0 – 5.5	1.7 – 2.0
Strawberry	6.0	1.8 – 2.2
Spinach	6.0 – 7.0	1.8 – 2.3
Lettuce	6.0 – 7.0	1.2 – 1.8
Cabbage	6.5 – 7.0	2.5 - 3.0
Broccoli	6.0 – 6.8	2.8 – 3.5
Asparagus	6.0 – 8.0	1.4 – 1.8
Bean	6.0	2.0 – 4.0
Basil	5.5 – 6.0	1.0 – 1.6

NUTRIENT CONCENTRATION

NUTRIENT	CONCENTRATION (g/l)
$N\text{-}NH_4$	0.54
$N\text{-} NO_3$	0.35
P	0.40
K	0.35
Ca	0.17
Mg	0.08
Na	0.04
Fe	0.09
Zn	0.03
B	0.03
Cu	0.04

SOIL VERSUS HYDROPONICS/AEROPONICS

There is no physiological difference between plants grown hydroponically/aeroponically and those grown in soil. In soil, both the organic and inorganic components must be decomposed into inorganic elements before they are available to the plant. These elements adhere to the soil particles and are exchanged into the soil solution where they are absorbed by plants. In hydroponics, the plant roots are moistened with a nutrient solution containing the elements. The subsequent processes of mineral uptake by the plant are the same.



ADVANTAGES

- Urban land scarcity and rising food demand make hydroponics a practical alternative to traditional farming in cities.
- Vertical hydroponic farming maximizes output per space, making it more efficient and profitable than traditional farming.
- Hydroponics produces cleaner, tastier crops without the need for pesticides.
- Hydroponics enables plants to reach their full growth potential by providing ideal conditions year-round.
- Hydroponics enhances nutritive value, leading to better-quality milk and healthier livestock.
- Hydroponics saves significant water and time, producing lush fodder in just 7 days with far less water than traditional methods.
- Hydroponic fodder is richer in proteins, vitamins, minerals, and bioactive enzymes than conventionally grown forage.
- Hydroponic fodder is tastier and more nutritious for livestock, while requiring much less labor to produce

DISADVANTAGES

- Expensive for long scale production
- The plant grower must need a specific level of proficiency to operate the system.
- The grower must have the information about the appropriate quantity of required nutrient for plant growth in the system.
- It is important to supply the required concentration of the nutrients. There is no any solid culture to absorb the excess nutrients if supply excess plant will die.
- The system design material is little expensive. As the well-designed system requires advanced equipment. It mainly constant high-pressure pumps, atomization nozzles, EC, and pH measuring devices, temperature, light intensity and humidity sensors and timer to control the system.

CONCLUSION

The hydroponics and aeroponics is extending worldwide and such systems offer many new opportunities for growers and consumers to have productions with high quality, including vegetables enhanced with bioactive compounds. As it is possible to cultivate soil less culture in very low spaces with low labor and short time, so hydroponics can play a great contribution for the poorer and landless people. Besides, it can improve the lifestyle of people and enhance the economic growth of a country. In India, the hydroponic industry is expected to grow exponentially in near future. To encourage commercial hydroponic farm, it is important to develop low-cost hydroponic technologies that reduce dependence on human labor and lower overall start up and operational costs.

REFERENCE

Al Meselmani, M. A. (2022). Nutrient solution for hydroponics. In Recent research and dvances in soilless culture. IntechOpen.

Gopinath, P., Vethamoni, P. I., & Gomathi, M. (2017). Aeroponics soilless cultivation system for vegetable crops. *Chemical Science Review and Letters*, *6*(22), 838-849.

Jones, J.B. 2005. Hydroponics: a practical guide for the soil less grower. CRC Press. Boca Raton. Fla.

Kumari, R., & Kumar, R. (2019). Aeroponics: A review on modern agriculture technology. *Indian Farmer*, *6*(4), 286-292.

Sardare, M. D., & Admane, S. V. (2013). A review on plant without soil-hydroponics. *International Journal of Research in Engineering and Technology*, *2*(3), 299-304.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Role of Micronutrients for Sustainable Agriculture

Yash Chauhan[1], Sandeep Singh[2], Shivam Pratap[3], Rajendra Singh Chauhan[4]

[1]M.Sc. Ag, Dept. of Soil Science & Soil Chemistry, RBS College, Bichpuri, Agra, U.P. 283105
[2]Subject Matter Specialist, Soil Science, Krishi Vigyan Kendra, Bichpuri, RBS College, Agra (U.P.)
[3]Subject Matter Specialist, Agricultural Extension, Krishi Vigyan Kendra, Bichpuri, RBS College, Agra (U.P.)
[4]Senior Scientist & Head, Krishi Vigyan Kendra, Bichpuri, RBS College, Agra (U.P.)
Corresponding Author Email: chauhanyc2002@gmail.com

Of the 17 elements known to be essential for plant growth, 8 are required in such small quantities that they are called micronutrients or trace elements. These elements are iron, manganese, zinc, copper, boron, molybdenum, nickel, and chlorine. The list in chronological sequence of discovery/establishment as micronutrients includes iron (Fe) in 1843, manganese (Mn) in 1922, boron (B) in 1923, zinc (Zn) in 1926, copper (Cu) in 1931, molybdenum (Mo) in 1939, chlorine (Cl) in 1954, and Nickel (Ni) in 1987. For operational purposes, micronutrients are classified into cations, viz., Fe, Mn, Zn, Cu, and Ni, and anions, viz., B, Mo, and Cl. Other elements, such as cobalt, silicon, vanadium, and sodium, appear to improve the growth of at least certain plant species. Animals, including humans, also require most of these elements in their diets. Some elements, such as selenium, chromium, tin, iodine, and fluorine, have been shown to be essential for animal growth but are apparently not required by plants. The terms micronutrient and trace element must not be construed to imply that these nutrients are somehow less important than macronutrients. To the contrary, the effects of micronutrient deficiency can be very severe in terms of stunted growth, low yields, dieback, and even plant death. By the same token, where they are needed, very small applications of micronutrients may produce dramatic results. Increasing attention is being directed toward micronutrient deficiencies for several reasons.

Forms in soil solution

The dominant forms of micronutrients that occur in the soil solution are listed in Table 1. The specific forms present are determined largely by the pH and by soil aeration (i.e., redox potential). The cations are present in the form of either simple cations or hydroxy metal cations. The simple cations tend to be dominant under highly acidic conditions. The more complex hydroxy metal cations become more prominent as the soil pH is increased.

Table 1: Forms of micronutrients dominant in the soil solution

Micronutrients	**Dominant soil solution forms**
Iron	Fe^{2+}, $Fe(OH)^{+2}$, $Fe(OH)^{2+}$, Fe^{3+}
Manganese	Mn^{2+}
Zinc	Zn^{2+} $Zn(OH)^{+}$
Copper	Cu^{2+}, $Cu(OH)^{+}$
Molybdenum	$MoO4^{-2}$, $HMoO^{-4}$
Boron	H_3BO_3, H_2BO^{-3}
Cobalt	Co^{2+}
Chlorine	Cl^{-}
Nickel	Ni^{2+}, Ni^{3+}

Source: Brady and Weil (2002)

Role of micronutrients

Micronutrients play many complex roles in plant nutrition. While most of the micronutrients participate in the functioning of a number of enzyme systems (Table 2), there is considerable variation in the specific function of the various micronutrients in plant and microbial processes. They are very vital for redox processes in plant cells by electron transfers and in the synthesis of growth substrates. These are constituents of prosthetic groups in several metal enzymes and activators of enzymatic reactions. Micronutrient stress influences the pollen viability, sink activity, higher activity of oxidase, hydrolytic catabolic enzymes, as well as production and translocation of photosynthates within plant parts.

Table 2: Functions of micronutrients in higher plants

Micronutrients	Functions in higher plants
Zinc	Present in several dehydrogenate, proteinase, and peptidase enzymes, promotes growth hormones and starch formation, promotes seed maturation and production.
Iron	Present in several peroxidase, catalase and cytochrome oxidase enzymes, found in ferredoxin, which participates in oxidation-reduction reactions (e.g. NO^{-}_{3} and SO^{-2}_{4} reduction and N fixation), important in chlorophyll formation.
Copper	Present in laccase and several other oxidase enzymes, important in photosynthesis, protein and carbohydrate metabolism, and probably nitrogen fixation.
Manganese	Activates decarboxylase, dehydrogenase and oxidase enzymes, important in photosynthesis, nitrogen metabolism and nitrogen assimilation.
Nickel	Essential for urease, hydrogenases, and methyl reductase, needed for grain filling, seed viability, iron absorption and urea and ureide metabolism (to avoid toxic levels of these nitrogen –fixation products in legumes).
Boron	Activates certain dehydrogenase enzymes, facilitates sugar translocation and synthesis of nucleic acids and plant hormones, essential for cell division and development.
Molybdenum	Present in nitrogenous (nitrogen fixation) and nitrate reductase enzymes, essential for nitrogen fixation and nitrogen assimilation.
Cobalt	Essential for nitrogen fixation, found in vitamin B12

Source: Brady and Weil (2002)

Diagnostic techniques for micronutrients in soils and plants

Different chemical extracting reagents were tried, established, and recommended to measure the plant available micronutrients from soils by several workers. In the majority of studies, 1N (NH4 OAc) at various pH with or without a combination of other reagents and DTPA + TEA buffer + $CaCl_2$ extracting solution was used for soil-available micronutrients. By and large, the DTPA extractable micronutrient method is relatively better than other methods in predicting deficiency of micronutrient cations in various soil groups. An amount of nutrient present in the plant is an indicator of the supply of that particular nutrient, which is directly related to the quantity present in the soil. These relationships between micronutrient soil tests vis-à-vis plant concentration and yield led to establishing critical concentration either in soil or in plant (Table 3).

Table 3: Critical levels of deficiency (CLD) of micronutrients in soils and plants used for delineation purpose

Element	CLD in soil		CLD in mature plant tissue (mg kg^{-1} dry matter)
	Extractant used	Value (mg kg^{-1})	
Zinc	DTPA	0.6	10-20
Iron	DTPA	2.5-4.5	50
Manganese	DTPA	2.0	15-25
Copper	DTPA	0.2	2-5
Boron	Hot water	0.5	5-30
Molybdenum	Ammonium Oxalate	0.2	0.03-0.15

Micronutrients in soils

The ranges of total and available amounts of micronutrients in Indian soils are presented in Table 4.

Table 4: Total and available micronutrients in Indian soils

Micronutrient	Total (mg kg^{-1} soil)	Available (mg kg^{-1} soil)
Zinc	20-97	0.12-2.80
Iron	11-141	0.15-5.33
Manganese	13,000-80,000	3.40-68.1
Copper	38-1941	4.0-102.0
Boron	2.8 to 630	0.04-7.40
Molybdenum	Traces to 12.3	Tr-2.80

Source: Rattan et al. (1999)

Multi-micronutrient deficiency

According to Singh (1991), the deficiency of individual elements like Zn (43%), Fe (9%), Cu (5%) and Mn (4%) was more prevalent as compared to that of two nutrients Zn+ Fe (4%), Zn +Cu (2.7%), Zn + Mn (1.9%) and Cu + Fe (1.2%). only 0.2-5.0 percent samples showed multi-micronutrient deficiencies. This clearly points out that single element deficiency is most wide spread in major soils of various states. Therefore, application of multi-micronutrient mixtures should be avoided as their use would be uneconomical and may also lead to degradation of soil environment and hence sustainability.

Diagnosis of micronutrient deficiencies

There are varied types of micronutrient deficiencies noticed in crop plants. Inadequate supply of micronutrients, initially forces plants to adjust themselves to manage the situation without exhibiting any symptoms but affecting growth and yield, referred as hidden deficiency, which would be extremely difficult even by leaf analysis unless the situation is critical. When the plant system is unable to cope up with hidden deficiency internally, then it losses its nutrient balance and exhibit specific disorder (s). In literature, some indicator plants are identified in respect of specific micronutrient deficiency.

Nutrient	**Indicator plant (s)**
Iron	Sorghum, barley, citrus, and peach
Zinc	Maize, onion, citrus, oats, pea, radish and wheat
Manganese	Apple, citrus, barley, maize, lettuce, oats, pea, radish and wheat
Copper	Apple, citrus, barley, maize, lettuce, oats, onion and tobacco
Boron	Lucerne, turnip, cauliflower, apple and peach
Molybdenum	Lettuce
Chlorine	Cauliflower, other Brassica sp, legumes, oat and spinach

Visual deficiency symptoms in crop plants

Zinc: Deep yellowing of whole leaves (cereals). Dwarfing (rosette) and yellowing of growing points of leaves and roots (dicots). The main vein of the leaf shows a loss of green color and becomes silver-white, and marked stripes appear in the middle of the leaf. Zinc deficiency symptoms in various crops are characterized as little leaf of citrus, mottle leaf of citrus, white bud of maize, rosette, sickle leaf or narrow leaf of cocoa, bronzing or khaira disease in rice, little leaf of mango, and resetting in cotton.

Boron: Death of growing points of shoots and roots. Failure of flower buds to develop. Boron deficiency in different crops is shown as heart rot of sugar beet, browning or hollow stem of cauliflower, top sickness of tobacco, heart rot of citrus, hard and misshapen fruits in citrus, hen and chicken in grapes, fruit cracking in pomegranate, die-back of growing points in cotton, shedding of bolls in cotton, and hollow heart of groundnut.

Iron: Symptoms of iron deficiency appear as chlorosis of the younger growth; severe deficiency results in bleaching, brown necrotic lesions on leaves, and die-back of young shoots. Interveinal yellowing of younger leaves with distinct green veins. Entire leaves become dark yellow or white with severe deficiency, and leaf borders turn brown and die.

Manganese: Interveinal tissue becomes light green with veins and surrounding tissue remaining green on dicots and long interveinal leaf streaks on cereals. Develop necrosis in advanced stages. Manganese deficiencies are named as grey speck of oats, speckled yellow of sugar beet, marsh spot of peas, black necrotic spots in potato, interveinal yellow spots in onion and tomato.

Copper: Yellowing of young leaves, rolling, and die-back of leaf tips. Leaves are small. Tillering is retarded. Growth is stunted. Copper deficiencies are identified as marginal wilting of tomato leaves, shriveled grains in cereals and aborted seeds in peas.

Molybdenum: Mottled pale appearance in young leaves. Bleaching and withering of leaves and sometimes tip death. Legumes suffering Mo deficiency have pale green to yellowish leaves. Growth is stunted, and seed production is poor. Molybdenum deficiency in crops is identified as whiptail in cauliflower, yellow spot of citrus, interveinal chlorotic rotting in cucurbits and spinach.

References

Brady, N.C., and Weil, R.R. (2002). The Nature and Properties of Soils. Thirteenth Edition, Pearson Education Asia, pp. 638-668.

Rattan, R.K., Saharan, Neelam, and Datta, S.P. (1999). Fert. News, 44 (2): 43-50.

Aquaculture Development of Small Indigenous Fish Species (SIFS): For Livelihood and Nutritional Security

Prem Kumar[1], Jagruti Mote[1], Munikumar Sukham[1], Bijay Kumar Behera[2] and Kedar Nath Mohanta[1]

[1]ICAR-Central Institute of Fisheries Education, Mumbai, 400061, India
[2]National Fisheries Development Board, Department of Fisheries, Government of India, Hyderabad, 500052, India

1. Introduction

Small Indigenous Fish Species (SIFS) of fish are a diverse group of native, small sized freshwater fish that inhabit various natural and manmade aquatic ecosystems such as rivers, beels, canals, ditches, rice paddies, ponds, and floodplains. These fish have historically been a staple in the diets of rural populations due to their widespread availability and nutritional richness. The SIFS is unique in that they are often consumed whole including bones, head, and internal organs which significantly enhance their nutritional value. This whole fish consumption provides an exceptional source of essential micronutrients like calcium, iron, zinc, iodine, and vitamin-A, as well as high quality protein and beneficial fatty acids. These species play a vital role in ensuring food and nutrition security for underprivileged communities, particularly in regions where diets are heavily carbohydrate based and lack nutritional diversity required for balanced nutrition. Importantly, SIFS contribute not just to daily nutrition but also to long term health and wellbeing of human by addressing public health concerns like vitamin A deficiency, anaemia (iron deficiency), and poor bone condition (calcium deficiency). Additionally, SIFS are abundant during specific seasons especially the monsoon and thrive with minimal human intervention. These species are often self-recruiting, meaning they naturally replenish in various aquatic systems without the need for hatcheries or intensive aquaculture management. From an ecological and economic standpoint, SIFS are crucial to sustainable livelihoods. They are naturally resilient, breed prolifically, and adapt well to both stagnant (lentic) and flowing (lotic) water bodies. Early aquaculture practices mistakenly viewed these species as pests or "trash fish" removing them to prioritize large commercial species. However, modern research and aquaculture practices have highlighted the benefits of integrating SIFS into polyculture systems, as they not only boost overall productivity but also maintain ecological balance. Moreover, their low market demand and ease of access often harvested as bycatch make them especially important for nutrient insecure households that cannot afford other protein rich foods. Recently, World Fish is implementing a GIZ-supported project called "Taking Nutrition-Sensitive Carp-SIFS Polyculture Technology to Scale", in Odisha and Assam states in India. Techniques have been successfully developed for farming SIFS in polyculture with carps, and in rice fields, but a lack of readily available SIFS seed produced by hatcheries is the key technical bottleneck inhibiting the scaling up of nutrition sensitive aquaculture (Rajts et al., 2022).

Fig. 1. Locally available SIFS in market of North Easter states of India

Despite their significance, SIFS remains under-researched, particularly regarding their captive seed production, farming and their conservational aspects. Due to high nutritional value and social relevance, SIFS holds immense potential in tackling malnutrition, rural economies of countryside population through development of SIFS aquaculture.

2. Small Indigenous Fish Species (SIFS)

Small indigenous fish species (SIFS) are defined as fishes, which grow to the size of 25-30 cm in matured or adult stage of their life cycle. They inhabit in natural water bodies like rivers and tributaries, flood plains, ponds, lakes, beels, streams, lowland areas, wetlands and paddy fields. In India 2,319 species of fin fish have been recorded out of which 838 from freshwater, 113 and 1,368 are from brackishwater and marine environment, respectively.

Fig. 2. Harvest of farmed Small Indigenous Fish Species (SIFS)

Out of 765 natives freshwater fish species documented so far, about 450 may be categorized as SIFS. Out of 450 SIFS, 104 species (23%) are very important. Out of 104 species of SIFS, about 62 species have been categorized as food fish, while 42 species as ornamental fish. Among SIFS, many species are cultivable and can be introduced as a candidate species in freshwater aquaculture system. These are *Amblypharyngdon mola*, *Notopterus notopterus*, *Puntius sarana*, *Labeo bata*, *Cirrhinus reba*, *Salmostoma bacaila*, *Nandus nandus*, *Anabas testudineus*, *Esomus danricus*, *Glossogobius giuris*, *Danio devario*, and *Chanda nama*, etc. Other potential species for aquaculture diversification are: small carps (*Labeo* sps.), small murrel (*Channa spp*), air breathing cat fish (*Heteropnustes fossilis*), non-air breading cat fish (*Mystus spp*, *Horabagrus brachysoma*, *Notopterus notopterus* and *Ompok pabda*) for which seed production and farming needed to be popularized and expanded. The maximum diversity of SIFS has been recorded from the North East region of the country followed by Western Ghat and Central India. Rural population of many parts of India are highly depend on indigenous species of fish for nutrition and livelihood security. Small indigenous fish species (SIFS) are an important source of essential macro- and micronutrients, which can play an important role in the elimination of malnutrition and micronutrient deficiencies in the rural communities (FAO, 2003).

Fig. 3. Traditionally cooked SIFS (*Mystus* spp)

3. Nutritional Value of Small Indigenous Species (SIFS) of Fish

SIFS is widely recognized not just for their abundance in freshwater ecosystems, but more importantly for their superior nutritional profile, especially in contexts where malnutrition and hidden hunger (micronutrient deficiency) are prevalent. These small fish are typically consumed whole, a practice that significantly enhances their nutritional benefit compared to filleted or large fish, where nutrient dense parts like the head, bones, and organs are often discarded. One of the most striking features of SIFS is their high concentration of essential micronutrients. Species like *Amblypharyngodon mola*, *Esomus danricus*, *Osteobrama cotio*, and *Corica soborna* are especially rich in vitamin A, which is crucial for maintaining vision, immunity, and cellular growth. Studies show that the vitamin A content in some SIFS species is so high that a small portion of these fish can fulfil a substantial part of the Recommended Nutrient Intake (RNI) for children and adults. In fact, 1.0 kg of SIFS may contain as much vitamin A and minerals as 50 kg of larger fish, such as Indian major carps (IMCs) (Roos *et al.*, 2007). In addition to vitamin A, SIFS are excellent sources of iron, zinc, iodine, calcium, and vitamin B12, all of which are commonly deficient in cereal based diets prevalent in low income households. Iron from SIFS, particularly from their blood rich organs, contributes to reducing anaemia; zinc supports growth and immune function; calcium from the bones aids bone development and maintenance; and vitamin B12, found in the flesh and organs, is essential for neurological health.

These nutrients are especially important in vulnerable groups like pregnant women, children, and the elderly (Suo *et al.*, 2021). SIFS also provide high quality animal protein and essential fatty acids like omega-3 fatty acid (EPA and DHA), which are key to brain and eye development and cardiovascular health. Unlike plant based sources, the protein in fish is more bioavailable, easily digested and absorbed by the human body. The fat content in SIFS, though lower than in marine fish, includes important polyunsaturated fatty acids that help reduce inflammation and support heart health (Thilsted *et al.*, 1997). Their nutrient profile is particularly beneficial in addressing what's called "double burden of malnutrition “where communities face both undernutrition and micronutrient deficiency. For resource poor food insecure households that may struggle to afford meat, dairy, or diverse vegetables, SIFS become an essential, low cost dietary component to meet daily nutrient needs (Banna *et al*., 2022). Furthermore, SIFS is seasonally abundant, especially during monsoon and floodplain expansion, making them a natural solution for seasonal dietary gaps. Integrating them into regular diets can drastically improve nutrient intake without major lifestyle or culinary changes, especially in regions where they are already part of traditional food systems. However, the nutritional richness of SIFS is not yet fully realised and utilized as well due to lack of awareness, limited data availability, underdeveloped processing methods, and low commercial value. Therefore, there is an urgent need for determining their nutrient composition, standardizing different processing methods, and suitable breeding and culture strategies for their year round availability in large quantity. In earlier days, a large variety of SIFS were available in paddy fields. But their diversity is lost in a very pace due to the use different agriculture chemicals like inorganic fertilizers and pesticides. So, conservation of biodiversity of this species is utmost important now. Enhancing awareness and accessibility of SIFS through nutrition sensitive policies could play a transformative role in public health nutrition.

4. Captive breeding potential of SIFS

Captive breeding refers to the controlled reproduction of animals, including fish, within specially managed environments rather than in their natural habitats. This practice has become an essential tool for conserving vulnerable or underutilized species, promoting sustainable aquaculture, and ensuring long term food and nutrition security. In the context of freshwater fish, especially **Small Indigenous Fish Species (SIFS)**, captive breeding holds significant promise. These small sized, nutrient dense fish are crucial in the diets of low income communities. However, many SIFS species face threats from habitat loss, overfishing, pollution, and being mistakenly treated as “trash fish” in intensive aquaculture systems. Captive breeding presents an opportunity to **protect and propagate these native species**, while also supporting **year round availability** and easing pressure on wild populations. The goal is not just to conserve these species, but also to **actively culture and promote them**, much like how larger commercial fish species (e.g., catla, rohu, pangas) that are cultured at present. This involves developing **dedicated breeding programs**, maintaining **genetic diversity** to avoid inbreeding, and mimicking natural environmental conditions such as appropriate water quality, space, temperature, and feeding patterns. By creating a **controlled breeding environment**, SIFS populations can be stabilized and farming practices can be promoted. This approach also allows researchers and fishery experts to study growth rates, reproductive behaviours, and micronutrient retention under captive conditions and the data generated from these studies can further improve farming and processing techniques. Moreover, **captive breeding of SIFS can play a critical role in sustainable aquaculture**, as these species are often prolific breeders, require minimal inputs, and coexist well with other fish in **polyculture systems**. This means that farmers can rear SIFS alongside larger fish to **increase overall pond productivity** while also diversifying the nutritional offerings from aquaculture. From a conservation standpoint, such programs can also safeguard **endangered or declining SIFS species** by maintaining broodstock in hatcheries and potentially reintroducing them into the wild when needed. Furthermore, increasing the captive bred supply of SIFS could reduce reliance on wild harvests and help **curb destructive fishing practices**, while opening doors to development of different **value-added products** for domestic consumption and export markets. The **captive breeding of SIFS** is a forward thinking approach to conserve and improve the aquaculture production, which will help in **food security of rural communities** It reflects a shift toward recognizing the immense potential of small fish not only as food but also as a sustainable, regenerative resource that deserves protection, propagation, and promotion just as much as any commercially dominant species.

SOME OF THE IMPORTANT SIFS

Fig 4. Puti (*Puntius sophore*)

Fig. 5. Climbing perch (*Anabas testudiens*)

Fig. 6. Pabda (*Ompok bimaculatus*)

Fig. 7. Gangetic Mystus, *Mystus cavasius*

References:

Kennedy, G., Nantel, G. and Shetty, P., 2003. The scourge of" hidden hunger": global dimensions of micronutrient deficiencies. Food Nutrition and Agriculture, (32), pp.8-16.

Chakrabarty, P. and Ng, H.H., 2005. The identity of catfishes identified as Mystus cavasius (Hamilton, 1822)(Teleostei: Bagridae), with a description of a new species from Myanmar. Zootaxa, 1093(1), pp.1-24.

Roos, N., Wahab, M.A., Chamnan, C. and Thilsted, S.H., 2007. The Role of Fish in Food-Based Strategies to Combat Vitamin A and Mineral Deficiencies in Developing Countries1. The journal of Nutrition, 137(4), pp.1106-1109.

Suo, L., VanBuren, C., Hovland, E.D., Kedishvili, N.Y., Sundberg, J.P. and Everts, H.B., 2021. Dietary vitamin A impacts refractory telogen. Frontiers in cell and developmental biology, 9, p.571474.

Thilsted, S.H., Roos, N. and Nazmul Hassan, N.H., 1997. The role of small indigenous fish species in food and nutrition security in Bangladesh.

Kumar, P., Biswas, G., Ghoshal, T.K., Kailasam, M., Christina, L. and Vijayan, K.K., 2019. Current knowledge on the biology, captive breeding and aquaculture of the brackishwater catfish, Mystus gulio (Hamilton, 1822): A review. Aquaculture, 499, pp.243-250.

Sarkar, U.K., Deepak, P.K., Kapoor, D., Negi, R.S., Paul, S.K. and Singh, S., 2005. Captive breeding of climbing perch Anabas testudineus (Bloch, 1792) with Wova-FH for conservation and aquaculture. Aquaculture Research, 36(10), pp.941-945.

NFDB,2018 , Package of Practices for Breeding and Culture of Commercially Important Freshwater Fish Species, p.e 45.

Rajts, F., Belton, B. and Thilsted, S.H., 2022. Selection of small indigenous fish for breeding trials in the states of Assam and Odisha in India.

Kunda, M., Khanom, M., Islam, M.J. and Pandit, D., 2024. Inclusion of near-threatened micronutrient-rich small indigenous species (SIS) dhela (Osteobrama cotio) in pond aquaculture. Aquaculture, Fish and Fisheries, 4(3), p.e189

Das, S., Nandi, S., Majumder, S. and Saikia, S.K., 2013. New characterization of feeding habits of Puntius sophore (Hamilton, 1822) through morphometry. J FisheriesSciences. com, 7(3), pp.225-231.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

ROLE OF PLANT GROWTH REGULATOR "AUXIN "IN VEGETABLE CROPS

Abirami K

PG Scholar, Department of Vegetable Science,
Horticultural College and Research Institute, TNAU, Periyakulam , Theni.

ABSTRACT

Vegetables have been a cornerstone of human nutrition since ancient times, and their production remains crucial for global food security. Plant growth regulators, such as auxin, play a vital role in optimizing vegetable yields and quality. Auxin, a phytohormone, is a key regulator of plant growth and development, influencing cell elongation, cell division, and tissue differentiation. In vegetable production, auxin modulates root architecture, stem elongation, and leaf expansion, ultimately affecting crop productivity and marketability. This project explores the mechanisms underlying auxin's action in vegetable crops, examining its impact on plant morphology, physiology, and yield. By elucidating the role of auxin in vegetable production, this research aims to inform the development of novel, auxin-based strategies for enhancing crop productivity, improving resource use efficiency, and ensuring sustainable food systems.

INTRODUCTION

Chemicals known as plant growth regulators (PGRs) can be manufactured or naturally occurring and affect a number of physiological functions in plants, including growth, development, and differentiation. Depending on their kind, concentration, and time of application, these compounds can either stimulate or impede plant development.

Growth regulators are organic chemical substances that, unlike nutrients, function in low concentrations to promote, hinder, or otherwise affect growth and development. Photosynthesis provides carbon and respiration provides energy for plant growth. Plant growth regulators (PGRs) are a category of compounds generated by plants that control plant growth and development. PGR is also known as phytohormone, plant hormone, bioregulator, or growth hormone.

Growth regulators (also called plant hormones) are naturally occurring or synthetic compounds that regulate and control various aspects of plant growth, development, and responses to environmental stimuli. These regulators are essential for processes such as germination, flowering, fruit development, root formation, and the plant's ability to adapt to stress. They function by influencing gene expression, cell division, elongation, and differentiation within plants.

Since prehistoric times, vegetables have been a part of the human diet. They continue to be a vital source of food for the world. The economic potential of each plant species and cultural setting restricts the usage of growth regulators. This can help veggies germinate more easily, produce more uniform crops, and be easier to harvest and store. The physiological activity of vegetable crops is regulated by the use of growth regulators, which ultimately increases vegetable yield.

Key Characteristics of PGRs:

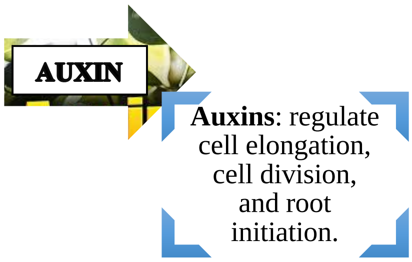
1. Hormone-like activity: PGRs mimic or interact with plant hormones, such as auxins, gibberellins, cytokinins, abscisic acid, and ethylene.
2. Low effective concentrations: PGRs are active at very low concentrations, often in the range of parts per million (ppm) or even parts per billion (ppb).
3. Specificity and selectivity: Different PGRs target specific plant processes or tissues, allowing for selective manipulation of growth and development.
4. Reversibility: In many cases, the effects of PGRs are reversible, meaning that plants can recover from treatment once the PGR is removed or its activity ceases.

Examples of Plant Growth Regulators:

1. Auxins (e.g., indole-3-acetic acid, IAA): regulate cell elongation, cell division, and root initiation.
2. Gibberellins (e.g., gibberellic acid, GA3): regulate seed germination, stem elongation, and flower formation.
3. Cytokinins (e.g., benzylaminopurine, BAP): stimulate cell division, differentiation, and nutrient mobilization.
4. Abscisic acid (ABA): regulates stomatal closure, water balance, and stress responses.
5. Ethylene: stimulates fruit ripening and senescence (aging).

ROLE OF AUXINS

The Role of Auxins in Plant Growth and Development Auxins are a class of plant growth regulators (PGRs) that play a critical role in numerous aspects of plant growth and development. The term "auxin" comes from the Greek word "auxein," meaning "to grow" or "to increase." Plants naturally create auxins, which are AUXIN mostly found in shoot apices (stem tips) and immature leaves.



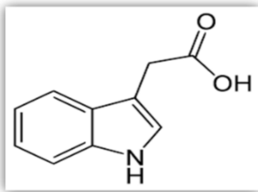
Key Roles of Auxins:

1. Cell Elongation and Cell Division: Auxins stimulate cell growth by increasing cell wall extensibility, allowing cells to expand and divide.
2. Apical Dominance: Auxins promote apical dominance by inhibiting the growth of lateral buds, ensuring that the terminal bud (apex) remains dominant.
3. Root Initiation and Development: Auxins induce root growth and differentiation, promoting the formation of adventitious roots (roots that arise from non-root tissues).
4. Tropisms: Auxins regulate tropic responses, such as phototropism (growth towards light), gravitropism (growth in response to gravity), and thigmotropism (growth in response to touch).
5. Fruit Growth and Development: Auxins are involved in fruit set and growth, particularly in the development of seeds and fruit tissues.
6. Senescence and Abscission: Auxins delay senescence (aging) and abscission (shedding of organs), helping to maintain plant tissues and organs.
7. Vascular Tissue Development: Auxins influence the formation and differentiation of vascular tissues (xylem and phloem), which are critical for water and nutrient transport.

Synthetic Auxins:

Several synthetic auxins are used in agriculture and horticulture, including:

1. **Naphthaleneacetic Acid (NAA)**: used for root induction, fruit thinning, and weed control.
2. **Indole-3-Butyric Acid (IBA)**: used for root induction, stem cutting propagation, and fruit growth regulation.
3. **2,4-Dichlorophenoxyacetic Acid (2,4-D):** used for weed control, fruit thinning, and growth regulation.



PLANT GROWTH REGULATORS	ASSOCIATED FUNCTIONS
AUXINS	Apical dominance, root induction control fruits drops, regulation of flowering, parthenocarpy, phototropism, geotropism, herbicides, inhibit abscission, sex determination, xylem differentiation, nucleic acid activity.

Role Of Auxin on Tomato

Synthesized auxin is frequently used to promote fruit set in a variety of fruit and vegetable productions, including tomatoes. The application of NAA in tomatoes results in an increase in fruit diameter, and the application of NAA successfully improves fruit set in tomatoes. Additionally, as the concentration of auxin increases, the percentage of flower clusters increases significantly.

In BARI tomato 7, Manik, and Ratan varieties, the combined application of IAA significantly influenced the number of days needed for 50% flowering, days needed for fruit setting, fruit cluster per plant , and fruit per plant. Beta-naphthoxyacetic acid (BNOA) has a positive effect on seed germination and fruit set, and earlier flowering in tomatoes. The application of 4-CPA in summer tomatoes increases the number of tomato fruit set. The application of 4-CPA hormone has a significant effect on the tomato fruit set; spraying tomato plants with NAA 0.2 ppm and 0.1 ppm gave significantly increased fruit set, and the number of days needed to fruit setting was significantly reduced compared to control.

IAA promotes cell elongation by activating wall-loosening factors, including elastins. This action is enhanced when gibberellins are also present. IAA can induce cell division when cytokinins are present. IAA promotes the development and organization of phloem and xylem.

When a plant is injured, IAA may stimulate cell differentiation and regeneration of vascular tissues.

Role Of Auxin on Cucumber

Auxin is essential for controlling the growth of the cucumber's roots, shoots, leaves, tendrils, flowers, and fruits. It does this mainly by affecting cell growth and elongation, but it also has a major effect on encouraging the development of female flowers and influencing fruit set and size. In other words, auxin application can increase the proportion of female to male flowers on a cucumber plant.

Auxin is essential for the cucumber plant's root development. From directed growth to lateral and adventitious root expansions, auxin effect is crucial. Plant growth and development rely heavily on adventitious roots (ARs) and lateral roots (LRs), which originate from stem and root tissues, respectively. Several studies have shown that auxin regulates the development of cucumber ARs and LRs.

Cucumber cultivation often occurs in a protected environment, however tendrils can cause chaotic development and increase crop management effort. Several cucumber mutants without tendrils have been previously reported. Auxin regulates the growth and number of cucumber tendrils.

Auxins play a crucial role in regulating cucumber traits such as fruit setting, length, shape, and trichomes/fruit spines. There are two types of fruit setting: pollination-dependent and parthenocarpic. Exogenously applied auxins can induce parthenocarpic fruit in cucumbers.

Role Of Auxin on Bell Pepper

IAA controls fruit growth and development, affecting size, shape, and quality. increases cell elongation and division, resulting in longer stems and larger leaves. improves root growth and development by increasing water and nutrient intake. Controls phototropism, which directs stems toward light sources, and gravitropism, which controls stem and root direction. Auxin is involved in stress-related gene expression, which aids plants in dealing with environmental stressors.

Table 1. given below explains about the different auxin used in the vegetable and their role.

S. No.	Vegetable Crop	Auxin Used	Concentration (ppm)	Role/Function
1	Tomato	IAA / NAA	20–50 ppm	Induces parthenocarpic fruit set, improves fruit size
2	Brinjal (Eggplant)	NAA	50 ppm	Promotes root initiation in cuttings, enhances fruit set
3	Chilli	NAA	40–50 ppm	Increases fruit set and reduces flower drop
4	Cucumber	IAA / NAA	50 ppm	Induces parthenocarpy and enhances fruit development
5	Onion	IAA	100 ppm	Enhances bulb formation and seed germination
6	Potato	IAA	100 ppm	Promotes tuber initiation and uniform growth
7	Carrot	NAA	20–30 ppm	Promotes root elongation and better shape
8	Cabbage	NAA	50 ppm	Increases head size and delays leaf senescence
9	Cauliflower	NAA	40 ppm	Improves curd development and yield
10	Lettuce	IAA	30–40 ppm	Enhances leaf expansion and delays bolting

Role Of Auxin on Carrot

Auxin essentially promotes healthy root growth and structure in carrots by controlling apical dominance, which can affect the number and arrangement of lateral branches on the carrot plant, and regulating root development, especially the initiation and elongation of the taproot, through cell division and enlargement.

The role of auxin in somatic embryogenesis was caused changes in the amounts of 2,4-dichlorophenoxyacetic acid (2,4-D), indole-3-acetic acid (IAA), and its conjugates in callus suspension cells and developing Daucus carota embryos. On 2,4-D-supplemented media, both embryogenic and non-embryogenic lines grew at comparable rates and levels of IAA and 2,4-D.

CONCLUSION

Plant growth chemicals play a crucial role in the growth and development of crops, including vegetables. Crop growth is impacted by changes in endogenous hormone levels caused by biotic and abiotic stress. Exogenous growth agents can be used to boost yields or sustain crops. Hormones typically travel between production and action sites inside plants.

Auxins are integral to the growth and development of plants. Their role in promoting root development, regulating stem growth, influencing fruit set, and coordinating responses to environmental stimuli makes them indispensable in both natural plant growth and agricultural practices. By manipulating auxin levels, farmers and horticulturists can enhance crop yield, improve plant health, and optimize production systems.

Physiological intercellular messengers known as phytohormones are essential for regulating every stage of a plant's life cycle, including germination, roots, growth, blooming, fruit ripening, foliage, and death. Furthermore, environmental variables like nutrient supply, drought, light, temperature, and chemical or physical stress cause plants to release hormones. As a result, hormone levels vary throughout a plant's life cycle and are influenced by the environment and season.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

The Economic Impact and Importance of Proper Poultry Feed Storage

Dr. Susmita Thullimalli

Associate Professor, Poultry Science, NTR College of Veterinary Science, SRI Venkateswara Veterinary University

Abstract

Poultry feed constitutes the highest recurrent cost in poultry production, accounting for up to 70% of total input expenses. Efficient feed management — including storage, processing, and utilisation — is therefore essential to reduce waste, enhance productivity, and improve profitability. This article explores the economic implications of feed mismanagement and highlights effective strategies in storage, processing, and feeding practices. Integrating modern technologies and veterinary control measures can significantly boost feed efficiency and reduce environmental and economic losses.

1. Introduction

Poultry farming plays a pivotal role in global food security by providing affordable sources of protein through eggs and meat. However, the profitability of poultry enterprises is heavily dependent on efficient feed utilisation. Losses due to poor feed storage and inefficient feeding strategies can significantly reduce production output. Proper storage, processing technologies like pelleting, waste management, and nutritional optimisation can address these challenges effectively.

2. Significance of Feed Storage

2.1 Economic Implications

Field studies conducted in Egypt reported mold levels of 22,000 c.f.u./g in improperly stored feed, compared to an acceptable threshold of 5,000 c.f.u./g (Hussein et al., 2018). This resulted in lowered feed conversion ratios and growth performance. A 20-tonne feed silo, which can be recovered within three years, could prevent losses amounting to US$300 annually. In hot and humid climates like India or Southeast Asia, these losses could be significantly higher due to increased fungal activity and spoilage.

2.2 Best Practices

According to FAO guidelines (2022), proper feed storage should involve:

- Use of waterproof and rodent-proof silos or containers
- Regular rotation of feed stocks (first-in, first-out)
- Control of temperature and humidity to prevent mycotoxin development

3. Feed Processing: The Value of Pelleting

Pelleting increases the bulk density of feed, enhances digestibility, and improves feed conversion efficiency (FCR). According to a meta-analysis by Abdollahi et al. (2013), pelleted feeds improve FCR by 3–8% compared to mash feeds in broilers. However, every 10% increase in fines (broken pellets) can lead to a 0.01% drop in FCR. Quality pelleting involves:

- Maintaining optimal pellet durability index (PDI) >85%
- Minimising pellet breakdown during transport
- Conditioning feed to the right moisture and temperature

Table 1 - Performance of broiler chickens fed pelleted and ground feeds at 8 weeks

Experiment	Weight gain (g)		Feed/gain	
	Pelleted	Ground	Pelleted	Ground
1	1,870	1,760	2.30	2.35
2	1,960	1,830	2.27	2.36
3	1,820	1,730	1.86	1.92

4. Feed Waste and Rodent Control

4.1 On-Farm Losses

Feed can be wasted before ingestion due to feeder design, overfilling, or bird behavior. Improper beak trimming may lead to feed spillage, especially in layer birds. Studies show that feed spillage can account for up to 10% of total feed losses if feeders are not calibrated (Scheideler, 2007).

4.2 Rodent Impact

Rats can consume up to 250g of feed daily and contaminate 10 times that amount with droppings and urine. This results in both direct consumption loss and indirect spoilage. Effective rodent control programs can reduce populations by up to 70% through trapping and habitat modification (Whisson et al., 2021).

Table 2 - Relationships of feed level within the feeders and the feed losses

Level of feed in feeders	Losses of feed
Full	20%
Two-thirds full	10%
Half full	3%
One-third full	1%

5. Protein and Energy Optimization

5.1 Phase Feeding

Step-down protein diets reduce nitrogen excretion and feed cost without affecting production. On a 100,000-bird farm, switching from a constant 16.5% protein diet to a step-down system can save 7.5 tonnes of protein and reduce 4.5 tonnes of nitrogen waste annually (Leeson & Summers, 2005). This aligns with environmental sustainability targets under integrated nutrient management systems.

5.2 Energy Cost Management

In broiler diets, energy accounts for the largest cost component. Reducing dietary metabolizable energy (ME) from 3,100 kcal/kg to 3,000 kcal/kg and supplementing with emulsifiers or enzymes (e.g., lysolecithin, phytase) maintains performance while saving €10–€12 per tonne (Cowieson et al., 2019). These additives enhance nutrient digestibility, allowing formulation flexibility.

Table 3 - Performance of laying hens on constant and step-down protein levels from 20-72 weeks of age

Protein level	Egg production (%)	Egg weight (g)	Feed intake (g/ hen/day)	Protein intake (g/ hen/day)	Protein (tonnes/100,000 hens)	N excretion (tonnes/100,000 hens)
Constant (16.5%)	70.9	58.2	99.3	16.4	105	63
Step-down[1]	70.5	57.5	99.6	15.2	97.5	58.5
[1]Protein Content (%)			Age period/weeks			
16.5			20-36			
15.5			36-48			
14.5			48-60			
13.5			60-72			

6. Enzyme Supplementation

Inclusion of enzyme blends (amylase, protease, phytase) at 1 g/kg in maize-based diets has shown to:

- Reduce ME by 145 Kcal/kg
- Lower amino acid levels by 4%
- Cut calcium and phosphorus by 0.10–0.12%

This substitution led to savings of US$11 per tonne without compromising bird growth (Olukosi et al., 2007). Moreover, adding phytase to rapeseed meal improved its value, potentially replacing soybean meal — a costlier protein source — with a saving of approximately US$130/tonne.

Table 4 - Cost broiler diet (with and without emulsifier) formulated with different ME levels

	With emulsifier	Without emulsifier
ME (kcal/kg)	3,000	3,100
Price €/T	361	373
Soya oil (%)	0.4	0.94
Animal fat (%)	6.18	7.69
Crude fat (%)	8.61	10.60
Grain (%)	67.49	64.42
SBM (%)	22.35	23.02

7. Internal Losses in Birds

7.1 Thermoregulation

Poor feather coverage in cold climates increases feed intake to compensate for heat loss. At 15°C, naked hens consume 40g more per bird compared to fully feathered birds. In Australia, this translated to an additional AUS$6.57 million in feed costs annually (Australian Egg Corporation, 2020).

7.2 Disease-Related Losses

Infection with diseases such as Gumboro, Coccidiosis, or Salmonella can reduce FCR by 25%, 18%, and 10%, respectively. Preventative veterinary programs, vaccination, and biosecurity can mitigate these losses and maintain feed efficiency.

8. Conclusion

Efficient feed management — from storage to feeding — is essential to achieve economic viability and sustainability in poultry production. Incorporating modern storage systems, adopting pelleting and enzyme technologies, implementing rodent control, and tailoring nutrient strategies to bird needs can substantially reduce waste and improve profitability. Moreover, integrating veterinary and environmental health considerations ensures long-term benefits in both performance and ecological impact.

References

Abdollahi, M.R., Ravindran, V., & Svihus, B. (2013). Pelleting of poultry diets: An overview with emphasis on pellet quality and nutritional value. *Animal Feed Science and Technology*, 179(1–4), 1–23.

Australian Egg Corporation. (2020). *Impact of feather loss on energy requirements and economics in laying hens*.

Cowieson, A.J., Singh, D.N., & Adeola, O. (2019). The use of enzyme technology in the nutrition of non-ruminant animals. *Animal Feed Science and Technology*, 250, 1–22.

FAO. (2022). *Guidelines on mycotoxin prevention in feed storage*. Food and Agriculture Organization of the United Nations.

Hussein, M., Ezzat, W., & Abdelrahman, H. (2018). Feed storage hygiene and mold growth: A case study in Egyptian poultry farms. *Journal of Poultry Science*, 55(4), 331–337.

Leeson, S., & Summers, J.D. (2005). *Commercial Poultry Nutrition* (3rd ed.). University Books.

Olukosi, O.A., Cowieson, A.J., & Adeola, O. (2007). Energy utilization and growth performance of broilers fed diets supplemented with enzymes. *Poultry Science*, 86(4), 777–784.

Scheideler, S.E. (2007). Management factors that impact feed wastage in layers. *Nebraska Poultry Reports*, Paper 12.

Whisson, D., Quinn, J.H., & Engeman, R.M. (2021). Rodent control in poultry farms: A systematic review of efficacy and methods. *Pest Management Science*, 77(5), 2179–2188.

FERTILIZER USE EFFICIENCY

Poornima S
PG Scholar, Department of Vegetable Science,
Horticultral College And Research Insititue, TNAU , Periyakulam, Theni

ABSTRACT
Fertilizer Use Efficiency (FUE) is a crucial factor in optimizing agricultural productivity while minimizing environmental impacts. Efficient fertilizer use ensures that crops receive the necessary nutrients for growth without excessive losses to the environment. Various factors influence FUE, including soil properties, fertilizer type, application methods, crop management practices, and climatic conditions. Strategies to enhance FUE include precision farming, balanced nutrient management, slow-release fertilizers, and integrated nutrient management (INM) approaches. Improving FUE not only boosts crop yields but also reduces nutrient runoff, mitigating soil degradation and water pollution. This paper discusses the principles of FUE, methods to assess it, and strategies for improving nutrient uptake efficiency in sustainable agriculture.

KEY WORDS: Integrated Nutrient Management (INM)**,** NanoCoteTM.

INTRODUCTION

Fertilizer is an essential component of food security and is necessary for the sustainable growth of crop production. Global agricultural development experiences have demonstrated that the most effective and significant strategy for boosting crop yields is sensible fertilization.

Only a percentage of the nutrients are used by the crop when fertilizer is administered, and not all of them are absorbed. The yield of any crop per unit of fertilizer applied under particular soil and weather conditions is known as fertilizer use efficiency. The results of soil tests that demonstrate a soil's capacity to supply nutrients serve as the basis for fertilizer recommendations. Since fertilizer is the most costly input, the objective is to use the fewest amount of key inputs to achieve the best economic output. Effective use and utilization of this costly input are crucial.

Since 1980, China's fertilizer use has been rising at a rate of 4% annually. Currently, China has emerged as the greatest fertilizer producer and user in the world. Although China's arable land only makes up 9% of the world's total, the country consumes about one-third of the world's fertilizer need. The nitrogen is lost significantly through volatilization, leaching, and runoff as a result of the low fertilizer usage efficiency (FUE).

FEATURES OF FERTILIZER

Fertilizer efficiency is determined by the type of fertilizer, the timing and method of application, and the mobility of the fertilizer's nutrients. Due to their high mobility,

- Nitrogenous fertilizers can move sideways as well as downhill.
- The phosphorus atom is quite immobile.
- Although potassium is likewise mobile, it is less mobile than nitrogen.

Phosphorus should be supplied as a basal dressing or close to the root zone, and N and K fertilizer should be treated frequently in divided dosages for optimal results.

INTERACTIONS BETWEEN VARIOUS FERTILIZER

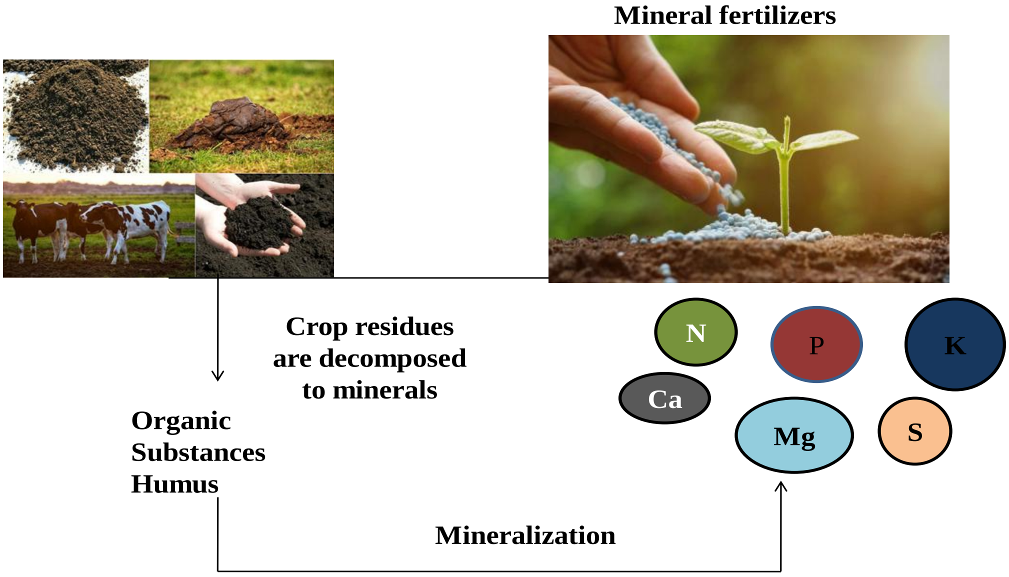
Mixing fertilizers with various nutrition carriers right before application is frequently standard procedure. If the following .fertilizers are combined with the fertilizer or amendment mentioned against them, their effectiveness will be reduced:

1. Ammonium sulfate and calcium carbonate
2. Ammonium sulphate and basic slag

These include,

Ammonium phosphate-basic slag, super phosphate-basic slag, and ammonium phosphate-calcium carbonate. All fertilizers can be combined with urea. You can blend different fertilizers.

ISSN : 3048 - 989X



Physical characteristics of the soil:

Compaction of the soil lowers the amount of fertilizer; temperature of the soil changes the solubility of fertilizers, the concentration of cations exchanged by the solubilized fertilizer; and the capacity of plants to absorb and utilize nutrients. Tillage, mulching, and irrigation are examples of popular management techniques that alter soil temperature to some degree.

Lack or excess of moisture in the soil is one of the most prominent issues in agriculture. Effective fertilizer management goes hand in hand with effective water management. Only when there is sufficient soil moisture present can fertilizers be used as efficiently as possible, and vice versa. While too much moisture causes the added fertilizer to drain out, too little moisture causes the additional fertilizer to be poorly available and the soil solution's osmotic pressure to rise because of the concentration of fertilizers in the soil.

Chemical characteristics of the soil:

The current pH of the soil affects the availability of nutrients for plants. Phosphoric fertilizers are not very effective in highly alkaline and acidic soils. In these cases, improving the soil's condition with the right additions might boost fertilizer effectiveness.

The following fertilizers should be given preference: physiologically acid fertilizers, such as ammonium sulphate, should be applied to alkaline soils, and physiologically alkaline fertilizers, such as calcium cyanamide basic slag, etc., should be applied to acid soils.

Leaching losses

Nitrate-containing fertilizers immediately drain out. More leaching occurs in sandier soils than in clavier soils. Although the loss in bare soil is higher than in cultivated soil, it can be somewhat reduced with the appropriate application method and timing. Leaching losses also occur when fertilizers containing urea and ammoniacal calcium cyanamide are applied to soils. Ammonium fertilizers are ineffective in extremely acidic soils or sandy acidic soils because ammonium ions cannot readily replace the aluminum ions in exchange sites.

When urea is added to paddy soil combined with crushed neem seeds, its efficiency is enhanced. These losses are more in the summer because nitrifying organisms oxidize ammonia, calcium cyanamide, and urea more quickly.

Reduced nitrifying organism activity results in less leaching loss. There are additional chemicals that reduce leaching loss and inhibit nitrifying organisms when used with nitrogen fertilizers. For example, N-serve (2-chloro-

6-trichloromethyl pyridine) @ 0.15-0.5 kg/ha (of applied fertilizer) and AM (2-Amino-4-chloro-6-methyl pyridine) @ 0.3-0.4%. 1.5% to 2.5% of fertilizer thiourea.

Impact of Soil Temperature on Nitrogen:

Temperature variations result in varying reactions to crop uptake of NH4 + and NO3 -- N fertilizers. N uptake from NH4 or NO3 fertilizers is nearly nonexistent below 13 °C; plants' highest uptake of N from NO3 and NH4 fertilizers is seen between 19 and 24 °C. Soil moisture determines how temperature affects fertilizer effectiveness.

Impact of Soil Temperature on Phosphorus and Potassium

As soil temperatures rise from 10 to 35 °C, phophatic fertilizers become much more effective, as shown by the fact that many plants absorb more P as temperatures rise. It is debatable how soil temperature affects the uptake of K ions from fertilizer and soil potassium. However, when soil temperatures rise to 24-28 °C, plants may absorb more K when low quantities of K fertilizers are applied.

Immobilization of nutrients in fertilizers

Nutrient elements may be immobilized or fixed or converted into unavailable forms by one or more of the following three means:

1. Chemical immobilization
2. Physiochemical immobilization
3. Microbiological immobilization

The effectiveness of water-soluble phosphorus is quite poor in acidic soils. Immediately, the water-soluble phosphorus is converted to insoluble phosphorus compounds. It is recommended to use insoluble phosphoric fertilizers, such as rock phosphates, in these types of soils. Further a thorough mixing of the phosphorus with soil increases the efficiency of the fertilizers. phosphoric fertilizers to calcareous soils invariably results in tricalcium phosphate, a compound from which phosphorus is not readily accessible. In these circumstances, water soluble phosphorus is somewhat more effective than water insoluble P, such as rock phosphate.

In soil containing undecomposed organic components with a high C/N ratio, microbial fixation of fertilizer and N could represent a significant challenge. This kind of immobilization only lasts a short while and can be avoided by applying more water-soluble N fertilizers or by giving the undecomposed organic matter enough time to completely decay.

Practical approaches to increase efficiency of fertilizers

Even at lower rates of fertilizer application, high-yielding crop types produce larger yields than local varieties that are not fertilized and exhibit a higher unit response to fertilizer. Therefore, to maximize the benefits of the fertilizers supplied, high-yielding types should be cultivated wherever possible. Maintaining an ideal plant population and optimal plant spacing are also crucial. To preserve fertility and productivity, make sure organic matter is recycled effectively. In general, soils that receive an adequate amount of organic matter exhibit a stronger response to a given nutrient. Make sure that enough nitrogenous fertilizers are added to soils when applying organic manures with a high C: N ratio in order to make up for the biological locking up of nitrogen in microorganisms. Adding a legume as an intercrop or as part of a rotating sequence. In addition to fixing air nitrogen, legumes change native phosphorus that is unavailable and precipitated or fixed fertilizer P into forms that are accessible. Avoiding excessive irrigation is advised since it causes N to be lost in wet situations. The soil shouldn't have too much water, especially while fertilizer is being applied. Once the extra water has been drained, fertilizer should be applied.

In dry seasons, crops react more strongly to phosphatic fertilizers. Based on the results of the soil test, balanced fertilizer should be used. The amount of additional nutrients in the soil determines how effective a straight fertilizer containing nutrients is. Generally speaking, phosphates work best when applied in full as a basal dressing, potash in full as a basal dressing or in part as a basal and the remainder in split doses, depending on the texture of the soil, and nitrogen in two to three split doses. For optimal plant availability, water-soluble phosphatic fertilizers should be spaced 4-6 cm from the seeds. Soil should be properly mixed with insoluble fertilizers. In certain cases, it is preferable to cure the urea by completely mixing it with five to ten parts soil and letting it sit overnight. This increases the pace at which urea is converted to ammonia carbonate. By combining the fertilizer with crushed require seed (5:1 parts), the N fertilizer's efficiency can be raised. Under specific soil and climate conditions, foliar fertilizer application should be used. An increasing number of people are suffering from zinc deficiency. Zinc sulfate is used in these situations at a rate of 10–25 kg. Using zinc sulfate as a base dressing improves the overall effectiveness of the other fertilizers applied in addition to correcting the zinc deficit.

Adverse soil condition should be corrected by using appropriate amendments, to get maximum benefit from fertilizer. Absence of weeds, pest and disease ensures the efficiency of fertilizer.

APPLICATION METHODS

1. **Soil Application:** May cause fixation in alkaline soils, but works well for Zn, Fe, and Cu.
2. **Foliar application**: Foliar application is more efficient for Mn and Fe, particularly in soils with a high pH.
3. **Fertigation**: Guarantees even dispersion and prompt accessibility.

WAY TO INCREASE FUE

By providing the crop with economically appropriate nutrients, nutrient usage aims to improve cropping systems' overall performance. To this end, NUE methodologies are defined below.

1) Scientific nutrient management
2) Integrated Nutrient Management (INM)
3) Use of modified fertilizers
4) Use of organic and green manures
5) Use of conservation tillage for proper crop residue management
6) Use of conservation tillage for proper crop residue management

1) Scientific nutrient management

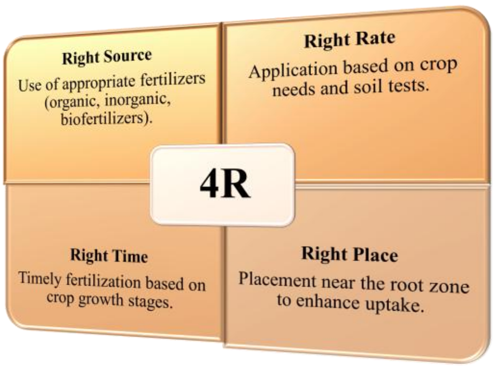
In cropping systems, appropriate nutrient management should aim to provide appropriate fertilizers according to crop demand and apply in a way that minimizes loss and maximizes use efficiency.

a) Right Rate:
The most crucial method for figuring out the soil's ability to deliver nutrients is soil testing; nevertheless, accurate calibration data is also required in order for the results to be effective in recommending the right fertilizer (IPNI, 2012b).

b) Right Time:
It is the interrelated to site specific nutrient management (SSNM). Greater synchronization between crop demand and nutrient supply is necessary to improve nutrient use efficiency, especially for N (Giller et al. 2004). Split applications of N during the growing season, rather than a single, large application prior to planting, are known to be effective in increasing N use efficiency.

c) Right Place:
Fertilizer application method is influenced use efficiency. Mainly two methods are used for fertilizer application, before and after planting. Determining of right placement is very important for deciding the rate of application.

4Rs of fertilizers application :



INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

2) Integrated Nutrient Management (INM)

In order to increase N and P recovery, INM makes the best use of locally available nutrient components, such as crop wastes, organic manure, biological N fixation, and chemical fertilizer, and their balancing interactions. Increasing returns to farmers in terms of yield, soil quality, and NUE of applied N requires a proper knowledge and utilization of these beneficial relationships among plant nutrients (Aulakh and Malhi, 2004).

3) Use of modified fertilizers

a) Slow-release fertilizer use:

According to Giller et al. (2004), a variety of slow-release fertilizers are currently available on the market and have the ability to improve NUE and decrease different N losses.

b) Nitrification inhibitors:

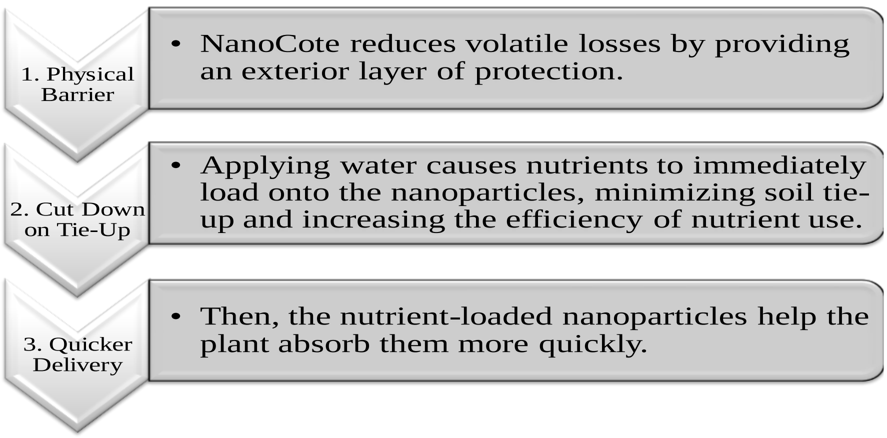
By ensuring a larger concentration of ammoniacal form of nitrogen in soil medium and preventing the conversion of ammonium-N into nitrate-N, nitrification inhibitors can be used to boost crop production and NUE (Shivay et al. 2001). Nitrogen stabilizers, such as nitrapyrin, DCD [dicyandiamide], and NBPT [n-butyl-thiophosphoric triamide], reduce the fertilizer's conversion to nitrate by blocking urease activity or nitrification.

4) Use of organic and green manures

5) Use of conservation tillage for proper crop residue management

6) Reducing losses of nutrients

Three levels of efficiency are added to your fertilizer investment by NanoCoteTM, which promotes quicker and more effective crop delivery while significantly lowering environmental losses:



CONCLUSION

Improving Fertilizer Use Efficiency (FUE) is essential for sustainable agricultural production, ensuring optimal crop growth while minimizing nutrient losses and environmental degradation. By adopting best management practices such as precision fertilization, balanced nutrient application, use of slow-release fertilizers, and integrated nutrient management (INM), farmers can enhance nutrient uptake and reduce waste. Additionally, soil health management, improved irrigation techniques, and advancements in biotechnology contribute to maximizing FUE. Enhancing efficiency not only boosts farm productivity and profitability but also promotes environmental sustainability by reducing soil depletion, water contamination, and greenhouse gas emissions. Therefore, a holistic approach integrating scientific advancements and farmer-friendly practices is key to achieving higher FUE and sustainable agricultural development.

References

Aulakh and Malhi. 2004. Fertilizer N use efficiency as influenced by interactions with other nutrients, In: Agriculture and the Nitrogen Cycle: Assessing the Impacts of Fertilizer Use on Food Production and the Environment (Editors: A.R. Mosier, J.K. Syers and J.R. Freney); 181- 191. Island Press, Washington, USA.

Baligar V.C., Fageria N.K. and He, Z.L. 2001. Nutrient Use Efficiency in Plants. *Communications in Soil Science and Plant Analysis*. 32(7&8), 921-950.

Giller, K. E., Chalk, P., Dobermann, A., Hammond, L., Heffer, P., Ladha, J. K., Nyamudeza, P., Maene, L., Ssali, H., & Freney, J. (2004). Emerging Technologies to Increase the Efficiency of Use of Fertilzer Nitrogen. In A. R. Mosier, J. K. Syers, & J. R. Freney (Eds.), *Agriculture and the Nitrogen Cycle: Assessing the Impacts of Fertilizer Use on Food Production and the Environment* :35-51. (Scope; No. 65).

Shivay, Y.S., Rajendra Prasad, Singh, S. & Sharma. 2001. Coating of prilled urea with neem *(Azadirachta indica*) for efficient nitrogen use in lowland transplanted rice (*Oryza sativa)*, Indian Journal of Agronomy 46(3): 453-457.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

The Future of Modern Mustard Oil: Canola-Safe, Nutritious and High Yielding

Yash Chauhan[1], Sandeep Singh[2], Shivam Pratap[3], Rajendra Singh Chauhan[4]

[1]M.Sc. Ag, Dept. of Soil Science & Soil Chemistry, RBS College, Bichpuri, Agra, U.P. 283105
[2]Subject Matter Specialist, Soil Science, Krishi Vigyan Kendra, Bichpuri, RBS College, Agra (U.P.)
[3]Subject Matter Specialist, Agricultural Extension, Krishi Vigyan Kendra, Bichpuri, RBS College, Agra (U.P.)
[4]Senior Scientist & Head, Krishi Vigyan Kendra, Bichpuri, RBS College, Agra (U.P.)

Among the seven main oilseed crops grown in India every year, rapeseed-mustard accounts for about 30% of the total oilseed production. It is mainly cultivated in Rajasthan, Madhya Pradesh, Uttar Pradesh, Haryana, Punjab, West Bengal, and Assam, and serves as a traditional and major source of edible oil in the country. However, rapeseed-mustard contains two harmful substances—erucic acid in the oil and glucosinolates in the leftover seed cake—which reduce its nutritional quality and raise health concerns. Erucic acid is associated with an increased risk of heart disease, while high glucosinolate levels render the seed cake unsuitable for animal feed. To make mustard oil and its by-products healthier and more acceptable, it is necessary to reduce these substances through genetic improvement.

Brassica crops—such as canola, mustard, cabbage, and broccoli—are among the oldest cultivated crops, with a history spanning over 5,000 years. *Brassica rapa* was historically grown across a wide region from Europe to China, while *Brassica napus* is believed to have originated in the Mediterranean and was cultivated in Europe during the Middle Ages, primarily for oil used in lamps. Today, *Brassica napus* L., commonly known as canola—a trademark from Canada—is the second most widely used vegetable oil crop globally. The name "Canola" also stands for Canadian Oil, Low Acid, and it was developed in Canada during the 1970s through plant breeding techniques. Because it contains very low levels of both erucic acid and glucosinolates, making it a healthier alternative to traditional oils. Since the 1970s, canola oil has gained popularity as a healthy cooking oil and is widely used in countries such as Australia, Japan, and Canada.

It is cultivated in Canada, Europe, China, India, Australia, and the United States. However, in Europe and parts of China, the winter-type *Brassica napus* is commonly grown, while in Canada and northern Europe, the spring-type is preferred. In areas with mild winters, such as Australia and the southeastern United States, spring-type canola is often sown in the fall to take advantage of favorable growing conditions. Although Indian mustard oil is rich in essential fatty acids (linoleic and linolenic) and low in saturated fats, its high content of erucic acid and glucosinolates limits its health benefits. Therefore, developing mustard varieties in India with canola-like quality has become an important goal for crop improvement. Table 1 shows the leading canola-producing countries, with Canada being the top producer at 18 million tonnes, contributing 30% to global production. China and India follow, producing 14.5 and 9 million tonnes, respectively, accounting for 24% and 13% of the world's share.

Table 1: List of Canola-Producing Countries

Country	**Canada**	**China**	**India**	**Germany**	**Australia**
Annual Production (Million Tonnes)	18.0	14.5	9.0*	4.2	3.8
Share of World Production (%)	30	24	13	7	6

**Note: India includes traditional mustard, not just canola.*

Nowadays in India, canola oil is gaining wide appreciation for its light taste, high smoke point, and heart-healthy profile, as it is low in saturated fats, erucic acid content and rich in omega-3 and omega-6 fatty acids. To better understand the unique qualities and advantages of canola oil, the following table 2 provides detailed information about its origin, composition, nutritional benefits, and agricultural importance.

Table 2: Nutritional Comparison of Canola Oil and Mustard Oil (per 100 g)

Nutrient	Canola Oil	Mustard Oil	Recommended Daily Intake (RDI)
Saturated Fat	7 g	12 g	<20 g (for heart health)
Monounsaturated Fat	61 g	59 g	No set limit, beneficial
Polyunsaturated Fat	28 g	21 g	11–22 g (depends on age/ gender)
Erucic Acid	< 2%	30–50%	0% (should be minimal)
Smoke Point	~220°C	~200°C	N/A
Omega-3 Fatty Acids	High (Alpha-linolenic acid)	Medium	1.1–1.6 g/day
Flavor	Mild	Strong	N/A
Vitamin E	Moderate (Natural antioxidant)	Moderate	15 mg/day
Shelf Life	12–18 months	6–12 months	N/A

Source: Canola Council of Canada, Food Composition Databases

Some Notified Varieties Developed in India

While canola (a specific type of rapeseed) is not traditionally grown, India has been working on developing canola-quality. To meet the growing demand for healthier edible oils and improve crop productivity, scientists developed several improved varieties of rapeseed-mustard with canola-quality traits (Table 3). These varieties are bred to have low levels of erucic acid and glucosinolates, ensuring better nutritional value and safety for both human consumption and animal feed. Additionally, these varieties are also more resistant to diseases and adaptable to different climatic conditions, making them suitable for cultivation across various parts in India.

Table 3: Some notified Canola Cultivars developed in India

Institution	Variety/ Year of Release
ICAR–Indian Institute of Mustard Research (IIMR), Bharatpur, AICRP-RM, PAU, Ludhiana	PGSH-51 (1996), PGSH-02 (2002), OCN-3 (2003), GSC-5 (2005), GSC-6 (2006), PGSH-1707 (2010), PAU Canola Hybrid 2 (2019),
National Research Centre on Rapeseed-Mustard (NRC-RM), Bharatpur	NRCYS 101 (2018)
The Energy and Resources Institute (TERI), New Delhi	NUDB-38 (2007), Phaguni (2009), NUDB-26-11, NUDH-07, CAN-138, TERI-Garima, TERI-Gaurav and TERI-Uttam (All 2010)
AICRP-RM, RARI, SKNAU, Durgapura (Jaipur),	RBN-0451 (2014)
AICRP-RM, SAREC, Kangra (SKUAST HP)	Him Palam Gobhi Sarson-1 (AKMS-8141) (2020)
AICRP-RM, ICAR-IARI, New Delhi	Pusa Mustard 32 (LES-54) (2022)
AICRP-RM, SKNAU, Jobner, Rajasthan	RBN-09151 (2022), RBN-10016 (2023)
AICRP-RM, SKUAST, Kashmir	AKMS-321 (2024)
NDRI, Karnal, India	NDR-9718

Information about Canola cultivation in India

Canola cultivation in India can be successfully carried out on 86 lakh ha (2024–25) in various types of neutral soils (pH 5.5–7.0). For this crop, selecting a well-drained loamy to clay loam soils It also has some tolerance to saline soils well-drained field is essential, as poor drainage during the winter season reduces the chances of crop survival. By following the recommended agricultural practices outlined in the attached table 4, farmers can achieve maximum yield.

Table 2: Detailed information about Canola

Category	**Details**
Season	Rabi Season
Seed Rate	4–5 kg/ha
Sowing Time	Mid-October to Mid-November
Spacing	Row to row: 30 cm & Plant to plant: 10–15 cm
Method of Sowing	Line sowing using seed drill or by broadcasting followed by light planking
Irrigation Requirement	2–3 irrigation:1st 25–30 days after sowing (DAS) 2nd – at flowering 3rd – at pod stage
Weed Management	20–25 DAS- Hand weeding- Use Pre-emergence: Pendimethalin @ 0.75–1.0 kg a.i./ha
Fertilizer Management	Basal FYM: 8–10 tonnes/ha- NPK (Recommended dose): 60–80 kg N, 40–50 kg P_2O_5, 20–30 kg K_2O per ha- Sulphur: 20–40 kg/ha (important for oil content)
Harvesting Time	February to March
Average Yield	1,300–1,500 kg/ha
Oil Content	38–42%
MSP	₹5,650/quintal (2023–24)
By-products	De-oiled cake (used as animal feed and organic fertilizer), biofuel potential
Post-Harvest Practices	Timely harvesting to avoid shattering; drying before storage

Conclusion

Canola cultivation represents a promising alternative to traditional mustard oil in India, offering significant health and nutritional advantages. With its low levels of erucic acid and glucosinolates, high omega-3 and omega-6 content, and good cooking qualities, canola oil has become increasingly popular among health-conscious consumers in India. Ongoing efforts by scientists to develop canola-quality rapeseed-mustard varieties through scientific breeding have led to the release of several improved cultivars. These improved varieties not only enhance the nutritional profile of edible oils but also increase yield potential. Furthermore, with 86 lakh hectares available for cultivation and appropriate agronomic practices in place, India has significant scope to expand canola production. By adopting these improved varieties and sustainable farming methods, Indian farmers can tap into the growing demand for healthier oils, contributing to both national nutritional security and agricultural profitability.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Decoding the genetic code of Photosynthesis: Exploring the Genes that Power Photosynthesis

Nisha. N.S.[1], Viji M.M.[1] and Rudranshu Sandip Khonde[2]

Department of Plant Physiology[1], Department of Genetics and Plant Breeding[2], College of Agriculture Vellayani, Thiruvananthapuram, Kerala- 695522

Abstract

Photosynthesis is a basic biological process that sustains life on Earth by converting solar energy into chemical energy. This complex process is orchestrated by genes located in both the nuclear and chloroplast genomes, requiring finely tuned coordination between the two organelles. Photosynthesis is based on light-dependent reactions and the Calvin-Benson cycle, involving numerous proteins that function in capturing light, transporting electrons, synthesizing ATP and NADPH, and fixing carbon dioxide into sugars. The chloroplast-encoded genes contribute to the components of the photosynthetic machinery, especially light dependent reaction, the majority of regulatory and structural proteins are encoded in the nucleus. Bidirectional communication—anterograde and retrograde signaling—ensures synchronized gene expression between the two genomes. This article explores the genetic architecture of photosynthesis, highlighting representative genes and their roles in energy production, carbon fixation, and gene regulation. Understanding these genetic interactions provides insights into improving photosynthetic efficiency, crop productivity, and sustainable bioengineering.

Key words: Photosynthesis, Light dependent reaction, Calvin Benson cycle, Nuclear encode genes, plastid encoded genes, anterograde and retrograde signalling, regulation of photosynthesis

Introduction

Photosynthesis is the biochemical process through which green plants, algae, and certain bacteria convert sunlight into chemical energy, and provides us the food we eat, air we breathe, and life on this planet sustain due to this process. Beyond its ecological significance, photosynthesis plays a central role in global carbon cycling and is a key target for efforts to enhance agricultural productivity and combat climate change.

But how do green plants and other photosynthetic organisms actually turn sunlight into the energy that fuels ecosystems? The answer lies in the tiny green factory and control system inside their cells: **chloroplasts** and **Nucleus**. The chloroplast not only capture light energy but also host the entire light-dependent reactions and part of the carbon fixation pathway. It operate in close coordination with the cell's nucleus, which encodes the majority of the proteins required for photosynthesis.

This dual genetic control system ensure that photosynthetic processes occur efficiently and adapt to changing environmental condition through two main signaling pathways, anterograde (nucleus to chloroplast) and retrograde (chloroplast to nucleus), signalling.

Turning Sunlight in to Life

Chloroplasts, capture the sunlight and converted it into usable biological energy. Using this energy green plants will fix the carbon dioxide (CO_2) into organic compounds- sugars, that are essential for life. The process in Photosynthesis is generally divided as

1. **Light-dependent reactions** –Occurs in the thylakoid membrane of chloroplast, sunlight is used to generate energy in the form ATP and NADPH through photolysis of water and electron transport chain.
2. **The Calvin-Benson cycle (or C3 cycle)** – Occurs in stroma of chloroplast, where energy captured in light dependent reaction will be is used to build sugars from CO_2.

These processes are controlled by hundreds of protein coding genes, with instructions stored in two different organelles: the nucleus and the chloroplast genome.

Genes Working in Harmony: Dual Genetic Control

Photosynthesis is a collaborative effort between the nuclear and chloroplast genomes. While the chloroplast retains a remnant of its ancient prokaryotic genome, most photosynthesis-related genes have transferred to the

ISSN : 3048 - 989X

nucleus over evolutionary time. To work efficiently, these two systems need to **communicate**. Coordination between nuclear and chloroplast genome are achieved through two types of signalling

- **Anterograde signalling**: from the nucleus to the chloroplast, regulating the expression of genes in chloroplast through sigma factors and RNA binding proteins.
- **Retrograde signalling**: from the chloroplast back to the nucleus, modulate gene expression in nucleus

This two-way communication ensures photosynthesis works smoothly.

Chloroplasts encoded genes

Chloroplasts have their own DNA, a remnant of their ancient origin as free-living cyanobacteria. Chloroplast genome encodes essential proteins for the light reactions of photosynthesis, rbcL gene codes for the large subunit of Rubisco, the key enzyme responsible for carbon dioxide fixation during the Calvin cycle. Multiple genes are involved in assembling the two major photosystems. The *psa* gene family encodes components of Photosystem I, while *psb* genes are responsible for building Photosystem II, both vital for capturing light energy and facilitating electron transport. The cytochrome b_6f complex and other components of the electron transport chain, are encoded by pet genes. Additionally, chloroplast atp genes family encode subunits of ATP synthase, including CF_0 components located in the membrane and CF_1 components present in the stroma. A list of key chloroplast-encoded genes and their functions is provided below (Table 1).

Table 1. Representative chloroplast-encoded genes, their function (Berry *et al.*,2013)

Gene	Protein/Enzyme	Function
rbcL	Rubisco (large subunit)	Photosynthetic carbon fixation
psaA-C, I, J	Photosystem I components	Electron transport
psbA-N, Tc, Z	Photosystem II components	
petA	Cytochrome *f*	
petB	Cytochrome b_6	
petD	Subunit IV of cytochrome b_6f complex	
petG, L	~4 kDa subunits of cytochrome b_6f complex	
atpF, H, I	CF_0 ATPase subunits (I, III, and IV) (transmembrane domain)	ATP synthesis
atpA, B, E	CF_1 ATPase subunits (α, β, ε) (stromal domain)	
rpl, rps	Large and small subunits of ribosomal proteins	Protein synthesis

These genes are transcribed and translated entirely within the chloroplast, using machinery that are similar to cyanobacteria.

Nuclear encoded genes

A majority of the proteins required for photosynthesis, particularly those involved in the Calvin cycle are encoded by nuclear genes. These genes are transcribed in the nucleus, and the resulting proteins are synthesized in the cytoplasm. They are then transported into the chloroplast via specialized plastid transit peptides. Once inside the chloroplast, these proteins perform essential functions such as light harvesting, electron transport, and sugar synthesis.

Notable examples include *RbcS*, which encodes the small subunit of Rubisco, the key enzyme for carbon fixation, and *Lhca* and *Lhcb*, which encode the light-harvesting antenna proteins for Photosystem I and Photosystem II, respectively. Similar to the chloroplast genome, nuclear genes also encode important components of the light-dependent reactions. For instance, the *Psa* gene family encodes proteins of Photosystem I, while the *Psb* genes contribute to the assembly of Photosystem II. The *Pet* genes encode various components of the electron transport chain, and the *Atp* gene family provides subunits required for ATP synthase function.

A list of representative nuclear-encoded genes involved in photosynthesis and their functions is summarized below (Table 2).

Table 2 Representative nuclear-encoded photosynthetic genes, their function in light depended reaction (Berry *et al.*,2013)

Gene	Protein/Enzyme	Function
RbcS	Rubisco (small subunit)	Photosynthetic carbon fixation
Rca	Rubisco activase	Dissociates sugar phosphates from Rubisco active site, facilitates carbamylation and activation
PsaD-H, K, L, N, O	Photosystem I components	Electron transport
Lhca1(Cab1)-6	Antenna pigment proteins of PSI	Light harvesting
PsbO-Tn, U, W-Y	Photosystem II components	Electron transport
Lhcb1(Cab1)-6	Antenna pigment proteins of PSII	Light harvesting
PetC	Rieske iron–sulfur protein subunit of cytochrome b_6f	Electron transport
PetM	~4 kDa subunit of cytochrome b_6f complex	Electron transport
PetE	Plastocyanin	Electron transport
PetF	Plastid ferredoxin	Electron transport
PetH	Ferredoxin–NADPH-oxidoreductase	Electron transport
AtpC, D	CF_1 subunits (γ, δ) – stromal domain	ATP synthesis
AtpG	CF_0 subunit II (transmembrane domain)	ATP synthesis

Table 3 Representative nuclear-encoded photosynthetic genes, their function in Calvin cycle (Berry *et al.*,2013)

Gene	Protein/Enzyme	Function
PGK	Phosphoglycerate kinase	Phosphoryl transfer to ADP producing ATP
GapA/B	Glyceraldehyde 3-phosphate dehydrogenase	Glycolysis
Pdk	Pyruvate orthophosphate dikinase	Production of phosphoenolpyruvate for initial CO_2 acceptance in C_4 plants
NADP-ME	$NADP^+$-malic enzyme	Biosynthetic pathways/photosynthetic. Plastid-localized form responsible for CO_2 assimilation in some C_4 plants
Ppc	Phosphoenolpyruvate carboxylase	Initial fixation of CO_2 into oxaloacetate in C_4 plants
CA1-3	β-Carbonic anhydrase	Catalyzes interconversion of CO_2 and bicarbonate for use by primary carboxylating enzymes.
PGK	Phosphoglycerate kinase	Phosphoryl transfer to ADP producing ATP

How The Light dependent reactions are regulated?

The light reactions of photosynthesis are powered by four main protein complexes embedded in the chloroplast's internal membranes:

1. **Photosystem II (PSII)** – Accept electrons from water and releases oxygen.
2. **Cytochrome b6f** – shuttles electrons, helping to pump protons across membranes.
3. **Photosystem I (PSI)** – creates energy-rich NADPH.
4. **ATP Synthase** – uses a proton gradient to make ATP, the energy currency of cells.

Each complex comprises proteins encoded by both nuclear and chloroplast genes (as detailed in Tables 1 and 2), highlighting the highly coordinated nature of the photosynthetic process.

The light independent reactions: Calvin-Benson Cycle

In the next stage of photosynthesis, the Calvin-Benson cycle uses utilizes ATP and NADPH to fix atmospheric CO_2 into carbohydrates. Most of the enzymes for this process are encoded in the nucleus as shown in Table 3, but Rubisco has one subunit from the chloroplast (rbcL) and another from the nucleus (RbcS). Together, they form a giant 16-part enzyme that's essential to life on Earth.

Regulating Photosynthesis: The harmony of Signals

Photosynthesis is a complex process controlled by hundreds of genes coded by both nucleus and chloroplast. The gene expressions are regulated by number of factors. Light is a major factor, additional inputs such as abiotic stress, energy status, and developmental stage also modulate the expression of photosynthetic genes through several interconnected layers of control:

- **Transcriptional Regulation:** Nuclear-encoded DNA-binding proteins modulate gene expression by activating or repressing transcription.
- **Post-Transcriptional Regulation:** RNA-binding proteins, predominantly encoded by nuclear genes, influence RNA stability, splicing, and translation within the chloroplast.
- **Photoreceptor-Mediated Control:** Light quality and intensity are sensed by photoreceptors such as phytochromes (responsive to red/far-red light) and cryptochromes (responsive to blue light), which fine-tune gene expression in both the nucleus and the chloroplast.
- **Redox Signaling:** The redox status of components such as plastoquinone (PQ) and its reduced form PQH_2, modulate nuclear and chloroplast gene expression

Coordinated Expression of Nuclear and Chloroplasts genome

In photosynthetic cells, a close coordination exists between the nucleus and the chloroplast, where signals from one can influence gene expression in the other. This bidirectional communication- anterograde from the nucleus to the chloroplast and retrograde from the chloroplast to the nucleus- ensures that photosynthesis operates efficiently and adapts to developmental cues, light conditions, and stress responses.

Conclusion

Photosynthesis isn't just about the sunlight and green leaves—it's a marvel of biological engineering, refined over billions of years. By decoding how genes from two different compartments work together, scientists are not only learning how life powers itself, but also opening the door to improving crops, fighting climate change, and designing sustainable technologies inspired by nature.

References

Berry, J. O., Yerramsetty, P., Zielinski, A. M., & Mure, C. M. (2013). Photosynthetic gene expression in higher plants. Photosynthesis Research, 117, 91-120.

Dent, R. M., Han, M., & Niyogi, K. K. (2001). Functional genomics of plant photosynthesis in the fast lane using Chlamydomonas reinhardtii. Trends in plant science, 6(8), 364-371.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Nitrous Oxide a Silent Threat to India's Climate

Harshitha K C[1], Rajeshwari N[2], Arjun M S[3] and Praveen R Shindhe[4]

[1]Research Scholar, Department of Extension and Communication Management, College of Community Science, UAS, Dharwad, Karnataka

[2]Professor & Head, Department of Extension and Communication Management, College of Community Science, UAS, Dharwad, Karnataka

[3]Research Scholar, Department of Extension and Communication Management, College of Community Science, UAS, Dharwad, Karnataka

[4]Associate Professor in Commerce, GFGC Dharwad

Email: rajeshwarinavaneeth@gmail.com

Introduction

Nitrous oxide is a potent greenhouse gas that often escapes public attention in favour of carbon dioxide or methane, yet it has a global warming potential nearly 270 times greater than carbon dioxide over a 100-year period. Beyond trapping heat, nitrous oxide persists in the atmosphere for more than a century and contributes to ozone layer depletion, amplifying ultraviolet radiation at Earth's surface. In India, nitrous oxide emissions account for over five percent of the nation's total greenhouse gases, with the country ranking among the world's top four emitters. As India balances its ambitions for food security and rural development with international climate commitments, addressing this "silent" driver of warming is increasingly critical.

The Dual Climate and Ozone Impact of nitrous oxide

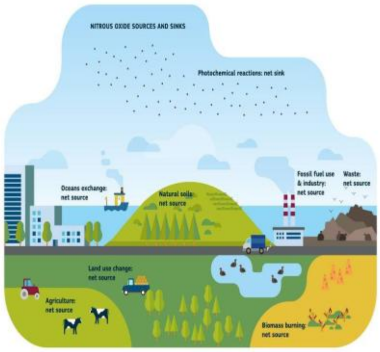
Once released, nitrous oxide molecules absorb infrared radiation in atmospheric windows where other gases are less active, intensifying the greenhouse effect. When they migrate into the stratosphere, they undergo photolysis and react with excited oxygen atoms to form nitrogen oxides that catalyse ozone breakdown. This dual role means that unchecked nitrous oxide emissions not only raise global temperatures but also degrade the Earth's natural sunscreen, that is ozone layer that increases risks of skin cancer and ecosystem disruption. Scientific assessments warn that without deep cuts in nitrous oxide exceeding 40 percent by mid-century the world cannot stay on a pathway to limit warming to 1.5 °C under the Paris Agreement framework.

Agricultural Origins: The Engine of India's nitrous oxide Emissions

In India, agriculture is the dominant source, responsible for 70 percent of national nitrous oxide output. Within this sector, emissions arise predominantly from two processes. First, the widespread application of synthetic nitrogen fertilizers exceeding 100 million tonnes annually creates soil conditions where nitrifying and denitrifying microbes convert excess nitrogen into nitrous oxide. Second, direct emissions from livestock manure management add to the burden. Both sources are exacerbated by the drive for higher yields and limited access to precise soil testing, resulting in habitual over application of fertilizers. In some regions, open-field burning of crop residues contributes marginally but still adds to total nitrous oxide released.

Industrial and Other Sector Contributions

Although agriculture dominates, other sectors also emit nitrous oxide. The industrial manufacture of nitrogen fertilizers releases significant quantities during the Haber-Bosch ammonia synthesis and nitric acid production, with roughly 38 percent of fertilizer associated with nitrous oxide arising from manufacturing and an additional 2.6 percent from fertilizer transportation. In plants lacking modern abatement technologies such as selective catalytic reduction these emissions remain unchecked. Meanwhile, energy production, manufacturing industries, and waste-water treatment collectively contribute about 30 percent of India's nitrous oxide, highlighting the need for cross-sectorial mitigation.



Trends in Emissions and National Inventories

India's nitrous oxide emissions have climbed steadily over the past three decades, nearly doubling since 1990 and reaching record highs by 2023. Official inventories show agricultural soils alone emit 89 percent of the sector's nitrous oxide, with energy at 16 percent, waste at 12 percent, and industrial processes at 2 percent of the national total. Government reports underscore that reducing nitrous oxide emissions is vital for meeting India's nationally determined contributions under the Paris Agreement and for protecting human health and ecosystems from the dual threats of climate change and ozone depletion.

Policy Responses and Flagship Programmes

Recognizing the challenge, the Indian government has launched several initiatives. Since 2016, the mandatory production of neem-coated urea which slows nitrogen release in soil has improved nitrogen use efficiency and achieved emission reductions equivalent to 26.81 million tonnes of carbon dioxide over 2019–2024. The National Innovations in Climate Resilient Agriculture (NICRA) programme promotes resilient farming techniques, including soiltest-based fertilizer application, zero tillage, crop residue management, legume rotations, and use of organic manures. The Soil Health Card Scheme further empowers farmers by providing field-specific nutrient recommendations, enabling judicious fertilizer use and reducing surpluses that drive nitrous oxide formation.

On-Farm Solutions: Precision and Biological Approaches

Precision agriculture represents a cornerstone of future mitigation. By combining gaps enabled fertilizer spreaders with real-time soil nutrient mapping, farmers can apply nitrogen only where and when crops need it, cutting surplus applications by up to 30 percent. Enhanced formulations such as urea coated with neem oil or synthetic nitrification inhibitors delay microbial conversion pathways that produce nitrous oxide. Additionally, incorporating organic amendments like biochar and compost promotes soil microbial communities capable of reducing nitrous oxide to harmless nitrogen gas. Crop rotations that include legumes harness biological nitrogen fixation, reducing dependence on synthetic inputs.

Industrial Abatement and Technological Upgrades

In parallel, industrial sources demand attention. Retrofitting fertilizer and chemical plants with selective catalytic reduction or non-catalytic reduction systems can abate over 90 percent of process-related nitrous oxide. Financial incentives and regulatory mandates to adopt these technologies are essential. Moreover, optimizing energy efficiency in ammonia synthesis and improving leak detection in transportation networks can further curtail indirect emissions.

Co-Benefits for Health, Water, and Ecosystems

Reducing nitrous oxide yields far-reaching co-benefits. Lowering fertilizer surpluses limits nitrate leaching into waterways, protecting aquatic ecosystems and human drinking supplies. Cleaner air through reduced release of ozone precursors and particulate matter translates into fewer respiratory diseases and premature deaths. Protecting the ozone layer diminishes harmful UV radiation, safeguarding crop productivity and public health. Thus, integrated nitrogen management aligns climate goals with sustainable development objectives.

The Way Forward

To achieve substantial nitrous oxide reductions, India must expand access to soil testing laboratories, scale up precision farming technologies, and deepen outreach to smallholder farmers. Mandating advanced fertilizer formulations and enforcing industrial emission standards will close significant gaps. International collaboration under climate and ozone protection frameworks can facilitate technology transfer and finance, accelerating deployment of low-emission solutions. By uniting policy, innovation, and community engagement, India can slash nitrous oxide emissions by at least 40 percent, securing a more resilient climate future while sustaining agricultural growth and rural livelihoods.

Reference

FAO. (2022). FAOSTAT Emissions Database. Food and Agriculture Organization of the United Nations.

Indian Ministry of Agriculture & Farmers Welfare. (2023). Soil Health Card Scheme. https://soilhealth.dac.gov.in

National Institute for Transforming India (NITI Aayog). (2023). India's Greenhouse Gas Inventory Report. https://www.niti.gov.in

Ravishankara, A. R., Daniel, J. S., & Portmann, R. W. (2009). Nitrous oxide (N_2O): The dominant ozone-depleting substance emitted in the 21st century. Science, 326(5949), 123–125. https://doi.org/10.1126/science.1176985

Tian, H., Xu, R., Canadell, J. G., Thompson, R. L., Winiwarter, W., Suntharalingam, P., Davidson, E. A., Ciais, P., Jackson, R. B., Janssens-Maenhout, G., Prather, M. J., Regnier, P., Pan, N., Pan, S., Peters, G. P., Shi, H., Tubiello, F. N., Zaehle, S., & Zhu, Q. (2020). A comprehensive quantification of global nitrous oxide sources and sinks. Nature, 586, 248–256. https://doi.org/10.1038/s41586-020-2780-0

UNEP. (2024). Global Nitrous Oxide Assessment: Summary for Policy Makers. United Nations Environment Programme. https://www.unep.org

Venkatesh, M., Singh, A. K., & Ramakrishnan, B. (2023). Mitigation of Nitrous Oxide Emissions from Indian Agriculture through Improved Fertilizer Management. Environmental Science & Policy, 138, 27–36. https://doi.org/10.1016/j.envsci.2023.01.004

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Hydrocarbons A Necessary Bane to Climate Change

Arjun M S[1], Rajeshwari N[2], Harshitha K C[3] and Girijamma Mulimani[4]

[1]Research Scholar, Department of Extension and Communication Management, College of Community Science, UAS, Dharwad, Karnataka

[2]Professor & Head, Department of Extension and Communication Management, College of Community Science, UAS, Dharwad, Karnataka

[3]Research Scholar, Department of Extension and Communication Management, College of Community Science, UAS, Dharwad, Karnataka

[4]Associate Professor in Commerce, GFGC Dharwad

Email: rajeshwarinavaneeth@gmail.com

Introduction

Hydrocarbons are organic molecules composed solely of carbon and hydrogen atoms. They occur widely in nature, for example, the pigments found in plants such as carotenes and natural rubber are nearly 100% hydrocarbon – and they are flammable and release energy when burned, making them important fuels, like coal, oil and natural gas. In fact, hydrocarbons make up fossil fuels, and burning these releases large quantities of carbon dioxide (CO_2). Hydrocarbon fuels most of the vehicles, ships and aircraft, and even they serve as feedstocks for plastics, chemicals and fertilizers. One of the practical application is benzene (a simple aromatic hydrocarbon) is a precursor for many synthetic drugs. Thus hydrocarbons underlie modern energy and industry as they store dense chemical energy and are the main engine of human activities.

Types of Hydrocarbons

Hydrocarbons are broadly classified into aliphatic and aromatic types. Aliphatic hydrocarbons can be further categorized into alkanes, alkenes, and alkynes, based on the types of bonds between carbon atoms. Alkanes have only single bonds, alkenes have at least one double bond, and alkynes have at least one triple bond. Aromatic hydrocarbons, like benzene, are characterized by a ring structure with alternating single and double bonds. Some of the examples for hydrocarbons are,

- Methane (CH4): The simplest hydrocarbon and a major component of natural gas.
- Butane (C4H10): Used in lighters and as a fuel.
- Benzene (C6H6): An aromatic hydrocarbon, a building block for many organic compounds.
- Ethane (C2H6): A common component of natural gas.
- Hexane (C6H14): Used as a solvent.

Importance of Hydrocarbons

Hydrocarbons have been playing a vital role in economic development and still dominate energy supply, particularly in developing countries like India where around 89 per cent of its energy consumed is powered by fossil fuels. Even today coal forms the major chunk out of all the fossil fuels as it generates approximately 75 per cent of the country's electricity. Today, oil, natural gas and coal supply the majority of global energy. Transportation vehicles such as cars, trucks, ships, planes are powered almost entirely by hydrocarbon fuels like petrol, diesel and jet fuel. In industries, hydrocarbons are raw materials for plastics, medicines and fertilizers, for instance, many plastics and synthetic fibers are long-chain hydrocarbons. Even the construction of renewable infrastructure relies on hydrocarbons as steel and cement manufacturing consume large amounts of coal or natural gas. In a natural context, hydrocarbons are part of the Earth's carbon cycle, as the carbon in fossil fuels was once absorbed from the atmosphere by ancient life.

Environmental Impacts of Hydrocarbons

Hydrocarbon's extraction and use cause various local environmental problems:

Air Pollution: Combustion of hydrocarbon fuels emits not only CO_2 but also sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter and toxic volatile organic compounds. These pollutants cause smog, acid rain and respiratory illnesses. For example, gasoline additives like benzene produce ultra-fine carcinogenic particles when burnt.

Water and Soil Contamination: Oil spills and fossil fuel extraction (e.g. oil drilling, fracking) can contaminate ecosystems. Each hydraulic fracturing well may use millions of gallons of water and produce toxic wastewater containing heavy metals, organics, leaches into groundwater. Major oil spills such as Deepwater Horizon in 2010, release tens of millions of gallons of crude oil which devastated a huge marine life and coastlines.

Ecosystem Damage: Hydrocarbon pollution harms wildlife and habitats. Oil and gas operations can fragment landscapes and cause long-term soil pollution. Hydrocarbon combustion also contributes to atmospheric deposition of harmful materials, causing acid rain, ozone depletion, which can damage forests, crops and lakes.

Ocean Acidification: About 25% of the CO_2 emitted from fossil fuels dissolves in the oceans, forming carbonic acid. Over the past century, ocean acidity has increased roughly 30%, threatening coral reefs and shellfish.

Hydrocarbons and Climate Change

Burning hydrocarbons in the energy sector, specifically for fuel production and electricity generation is the largest source of anthropogenic greenhouse gases. Carbon dioxide (CO_2), the chief heat trapping gas from fossil fuel combustion has surged from approximately 280 ppm in pre-industrial times to over 422 ppm in 2024. This rise has driven a global temperature increase of about 1.3 °C above the late 19th century average. In 2024 alone, energy related CO_2 emissions hit a record 37.8 Gt. Notably, natural gas (a light hydrocarbon) saw a 2.5% rise in CO_2 emissions in 2024, the largest single contributor to that increase is coal. But oil also continues to emit huge amounts of CO_2 annually.

Hydrocarbon use also emits methane (CH_4), a powerful greenhouse gas. Methane has a much stronger warming effect per molecule than CO_2, about 28–36 times on a 100-year horizon. Roughly 60% of current global methane emissions are anthropogenic, and over one-third of those come from the oil, gas and coal industries. Methane released during drilling, venting or pipeline leaks causes an "instant super-charged" greenhouse effect. Because CH_4 also generates ground level ozone which is an another pollutant. Reducing this kind of methane leaks would cut both surface warming and local air pollution.

The net result of these greenhouse gases is a well-documented driver behind climate change, leading to more frequent extreme weathers including heatwaves, storms, droughts, rapid glacier and ice melt, and rising seas. For example, the U.S. alone suffered over 600 billion dollars in weather related damages between 2016–2020 attributable to climate change. Sea levels have risen about 9 inches since 1880, increasing coastal flooding risk. To summarize, hydrocarbons, through their CO_2 and CH_4 emission forms the dominant player in 1.3 °C warming and related impacts that we see today.

Mitigation Strategies

Reducing the climate impact of hydrocarbons is the need of the day. It requires both cutting emissions and transitioning to alternative sources of energy. Key strategies include:

- **Decarbonizing Energy Supply**: meaning completely eliminating the use of energy sources which release carbon upon using. It can be achieved by rapidly expanding renewable energy such as wind, solar, hydro and nuclear power and increasing energy efficiency. Global renewable power capacity grew at a record of 15.1% in 2024 by adding 585 GW to its previous year, but studies indicate that it must keep growing at more than 16 to 17% per year to triple capacity by 2030. Shifting towards sustainable transport, which uses renewable energy such as EVs directly displaces hydrocarbon fuel. Experts estimate that $4 trillion/year to 2030 investments in renewables could eventually save approximately 4.2 trillion dollars per year in avoided pollution and climate costs.
- **Improve Fossil Fuel Use**: In the near term, "bridge" fuels can reduce carbon intensity. For example, switching electricity generation from coal to natural gas such as methane has cut CO_2 per unit energy in developed nations since 2010. More efficient engines, vehicles and appliances also lower hydrocarbon demand. At the same time, strict controls on methane leaks in oil and gas – such as leak detection and equipment fixes – can rapidly curb warming. India is also combating the problem of unburnt fuel emission

by introducing its BS (Bharat Stage) standards. The latest BS6, or Bharat Stage 6, is the most advanced emission standards for vehicles in the country, equivalent to Euro VI norms. Implemented in April 2020, BS6 aims to significantly reduce air pollution from vehicles by setting stricter limits on pollutants like nitrogen oxides and particulate matter . This transition from BS4 to BS6 involved major changes for the Indian automobile industry, requiring upgrades to engine technology and fuel composition.

- **Carbon Capture and Storage (CCS)**: Capturing CO_2 before or after combustion and storing it underground can neutralize emissions from unavoidable hydrocarbon use. The IPCC (Intergovernmental Panel on Climate Change) notes that carbon removal is essential to reach net-zero emissions. Scaling up CCS, for instance at power plants, cement factories and hydrogen production units could prevent fossil CO_2 from reaching the atmosphere while the market transitions away from coal and gas.

Policy and Behavioral Measures: Governments must end fossil-fuel subsidies and impose carbon prices or caps. Removing subsidies (over 1.7 trillion dollars globally in 2022) would turn the economy towards clean energy. Land-use policies to protect forests, which absorb CO_2 and conservation (reducing wasteful fuel use) are also important. India had set a goal to achieve 500 GW of non-fossil fuel capacity by 2030, including a commitment to installing approximately 50 GW of non-fossil fuel power capacity annually starting from 2023. Recently India has hit a major clean energy milestone by achieving 50 per cent of its installed electricity capacity from non-fossil fuel sources, five years ahead of the 2030 target set under the Paris Agreement. According to official data, the country's total power generation capacity now stands at 484.8 GW, of which over 234 GW comes from non-fossil fuel sources, including solar, wind, large hydro, and nuclear. This shows the country's commitment towards the sustainable transition.

Technological Innovations: Continues R&D can shoot up possible use of alternatives. Green hydrogen which is produced from renewables and advanced biofuels could replace hydrocarbons in hard-to-abate sectors such as shipping, aviation, heavy industry, without CO_2 emissions. Breakthroughs in batteries, heat pumps and smart grids make electrification more feasible. Also there is an urgent need for upgradation of our energy storage infrastructure to efficiently store and transfer electricity produced from renewable sources like huge solar parks and wind turbines, ensuring a stable and reliable power supply. As India aims to increase its renewable energy capacity and achieve 'net-zero emissions' by 2070, energy storage will be crucial for managing the intermittency of these sources and meeting peak demand.

To conclude, hydrocarbons have undeniably shaped our modern civilization from the era of industrialisation, but with environmental cost. We can't ignore their high contribution to climate change. As we move forward, the global focus must shift from dependency on hydrocarbons to cleaner, more sustainable sources of energy. The future depends on collective efforts in the field of policymaking, scientific innovations, industrial practices and individual perceptions along with participation to mitigate the damage and build a resilient, climate safe planet.

References

Encyclopedia Britannica. (n.d.). How does the use of hydrocarbons affect global warming and climate change? https://www.britannica.com/question/How-does-the-use-of-hydrocarbons-affect-global-warming-and-climate-change

Environmental and Energy Study Institute. (2021). Climate, environmental, and health impacts of fossil fuels [Fact sheet]. https://www.eesi.org/papers/view/fact-sheet-climate-environmental-and-health-impacts-of-fossil-fuels-2021

International Energy Agency. (2025). Global energy review 2025: CO_2 emissions. https://www.iea.org/reports/global-energy-review-2025/co2-emissions

Ministry of New and Renewable Energy (MNRE), Government of India. (n.d.). Energy storage systems (ESS) overview. https://mnre.gov.in/en/energy-storage-systemsess-overview

Ritchie, H., Roser, M., & Rosado, P. (2024). CO_2 and greenhouse gas emissions. Our World in Data. https://ourworldindata.org/co2-and-greenhouse-gas-emissions

World Economic Forum. (2024, April). Renewable energy transition: Wind and solar power in 2024. https://www.weforum.org/stories/2025/04/renewable-energy-transition-wind-solar-power-2024

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

The Cultural and Historical Significance of Fish in Tamil Civilization

J. Bovas Joel, P. Elakkanai, M. Marimuthu, Ahamed Rashid

TNJFU - Dr. M.G.R. Fisheries College and Research Institute, Thalainayeru- 614712

Abstract

In Tamil civilization, fish are not just food or commerce but carriers of deep spiritual, artistic, and sociopolitical meaning. Their symbolic resonance and practical significance have coursed through centuries of Tamil history, particularly in the Neidal (coastal) zone. This maritime region fostered robust fishing communities whose way of life was interwoven with nature, reverence, and identity. Tamil classical texts, temple architecture, coinage, and foreign travelers' observations highlight fish as divine symbols, economic assets, and cultural motifs. This article explores how fish, as an emblem and entity, have remained central to Tamil livelihood and lore — offering a unique perspective on the maritime soul of South India and its ancestral intimacy with the sea.

Introduction

Tamil Nadu's long and inviting coastline has been more than a geographic feature — it has been the cradle of one of the world's most enduring seafaring cultures. Fishing was not merely an occupation but a way of life for coastal Tamils, whose songs, symbols, and stories are still soaked in brine. From early Sangam literature to royal seals, fish appear everywhere in Tamil civilization — testifying to their indispensability. Unlike the popular focus on inland temple cities like Madurai or agricultural plains like Tanjore, this narrative centers on the often-overlooked Neidal zone, where the sea was both a provider and a deity. Contributions like that of Dr. M. R. Perumal Mudaliar, especially his work presented during the 1969 CMFRI Symposium on Corals and Coral Reefs, help stitch together scattered yet vivid references to marine life in Tamil art, literature, and daily ritual.

Tamil Ecological Classifications and the Neidal Region

In the ancient Tamil worldview, nature was not generalized but categorized into five tinai or ecological zones — Kurinji (hills), Mullai (forests), Marudham (plains), Palai (drylands), and Neidal (coast). The Neidal region, marked by briny winds and open seas, had its own deities, music, and customs. The god Varuna was seen as protector of this seascape, invoked by fishermen for favorable tides and safe returns.

Sangam texts such as Perumpanatruppadai offer immersive glimpses into Neidal life: men setting out in coconut-shell boats, women preparing fish stew under palm leaves, and children playing on sandbars with shell ornaments. The Kayal, Iraa, and Vaalai fish were not just marine species but social commodities, forming part of meals, trade, and ritual offerings. These accounts underscore how fishing was a collective activity, built around kinship, environment, and reverence for marine cycles.

Kaviripoompattinam and Marine Rituals

Pattinappalai, another jewel in Sangam literature, details the bustling port town of Kaviripoompattinam (modern Poompuhar), where marine rituals flourished. The sea was not merely a backdrop to trade but an active spiritual force. Women would wear garlands made of marine leaves and perform sacred rites using saw-fish bones, embedding them into sand as a devotional act. The ritual sequence of first bathing in salty seawater and then in a freshwater river symbolized purification — of the body, spirit, and karmic residue.

These customs show an indigenous theology of the sea, where ecological elements like fish, salt, coral, and sea-shells were integrated into Tamil cosmology. Rituals became a form of environmental literacy — where knowing the rhythms of the tide and honoring marine species was as sacred as prayer.

Terminology and Classifications of Fishermen and Fish

The Tamil language's richness is evident in its nuanced terminology for both fishermen and fish. The fisherfolk were not a monolith but classified as Paradavar, Thimilar, Nulaiyar, Savar, Kadavar, and Pattinavar — each representing subtle variations in location, gear, or fishing techniques. This diversity reflected a detailed social understanding of marine expertise.

Lexicons like the 9th-century Chudamani Nighantu catalogued an impressive range of fish: Sura (shark), Iraal (shrimp), Kalai, Kendai, and Cel, among others. Fish were described based on attributes such as color, habitat, temperament, and mythic qualities. For instance, the Timingilam, a whale-like creature said to swallow elephants, reflects not just mythology but the awe with which the sea was regarded — powerful, mysterious, and potentially dangerous.

Fish as Royal Symbols and in Coinage

The Pandya dynasty, whose capital was Madurai, took the reverence for fish a step further by adopting it as their royal emblem. Coins, seals, and even flags bore images of single or double fish, denoting royal authority, fertility, and divine protection. These coins served both economic and symbolic purposes, as they traveled through trade routes and conveyed the power of the sea-oriented state.

When the Cholas later subdued the Pandyas, they did not erase the fish emblem — they appropriated it. The same fish, now a symbol of conquest, appeared on Chola coins and temple plaques, illustrating how deeply marine symbols had entered the fabric of Tamil political and cultural identity.

Fish as Architectural and Artistic Motifs

Tamil temple architecture provides another canvas where the marine world flourished. The Makara — a mythical sea beast combining parts of a crocodile, elephant, and peacock — featured heavily in temple design. Downspouts shaped like Makara heads, ornamental arches (makarathoranam), and stone sculptures in temple tanks reflect a stylized marine cosmology.

Jewelry design mirrored this aesthetic as well. Fish-shaped amulets, often made of gold and encrusted with gems, were found in temples and elite homes. Kings commissioned fish-shaped lockets as temple donations, turning marine motifs into both devotional and luxury items. These artifacts not only reveal the artisanal depth of Tamil culture but also the way marine life was spiritualized and aestheticized.

Traveler Accounts on Tamil Marine Wealth

The richness of Tamil marine life attracted foreign chroniclers who documented what they saw with both fascination and respect. Greek ambassador Megasthenes, for example, described the Makara and strange half-human fish along India's southern shores. He even categorized dolphins into gentle and violent types — a detail that implies active observation of Tamil fisheries.

Ibn Battuta's 14th-century travels reveal another dimension: the import and processing of Qulb-ul-mas, a type of fish from the Maldives, which was smoked and sold in Indian coastal markets. These references validate how Tamil coasts were part of larger Indian Ocean trade networks where fish played diplomatic, economic, and gastronomic roles.

Pearl Fishing and Maritime Economy

No discussion on Tamil marine wealth is complete without referencing pearl fisheries — particularly those near Korkai in present-day Tirunelveli. These fisheries were the economic bedrock of the Pandya kingdom, producing not just pearls but political clout. Classical authors like Ptolemy and Marco Polo wrote about the industry with admiration.

Pearl diving was seen as both dangerous and divine. Divers paid taxes not only to the king but also to Abraiaman, spiritual intermediaries hired to appease sea beasts and ensure a safe dive. The mention of oyster shoals following a "leader oyster" mirrors bee colonies, revealing how Tamil fishers observed and mythologized oceanic behavior. These practices show an industry that married economy with cosmology, transforming labor into ritual.

Conclusion

Through literature, ritual, trade, and design, the fish in Tamil civilization becomes more than a species — it becomes a symbol of existential truth. It embodies sustenance, sovereignty, spirituality, and style. Its presence in every cultural layer — from folklore to foreign accounts — reveals a deeply maritime consciousness that shaped Tamil identity as much as its land-based counterpaConclusi

In our contemporary era, where oceans face pollution, overfishing, and rising seas, the Tamil reverence for marine life offers crucial wisdom. It calls for coexistence, ecological balance, and cultural remembrance. To remember the fish is to remember the sea — not just as a resource, but as a sacred living system. In Tamil civilization, the fish is not just caught, it is honored — a token of survival, a metaphor for life, and a legacy that swims through time.

References

1. Sangam Literature: Perumpanatruppadai, Pattinappalai
2. Megasthenes, Ibn Battuta, Marco Polo, Aelian
3. Tamil Lexicons including Chudamani Nighantu
4. Epigraphical Records and Numismatic Sources of Pandya and Chola Eras
5. Proceedings of CMFRI Symposium (1969), Dr. M. R. Perumal Mudaliar

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Role of Conservation Agriculture in Carbon Foot Print Mitigation

Dr. Anand Kumar Jain, Shaheen Naz*, Dr. Prem Chand Kumar, Dr. Beerendra Singh, Dr. Suman Kalyani and Dr. Ranvir Kumar

Bihar Agricultural University Sabour - 813210

*Corresponding Author Email: shaheennaz9@gmail.com

Introduction:

Conservation agriculture (CA) plays a significant role in mitigating carbon footprints by reducing greenhouse gas emissions from agricultural activities and enhancing carbon sequestration in soil. CA practices like reduced or no-till farming, residue management, and crop diversification help to decrease soil erosion, improve water retention, and increase soil organic matter, all of which contribute to lower carbon emissions and improved soil health.

Conservation agriculture (CA) is a farming approach focused on maximizing crop yields while minimizing environmental impact. It centers on three core principles: minimum soil disturbance, permanent soil cover, and crop diversification. By adopting these principles, CA aims to improve soil health, enhance water and nutrient use efficiency, and increase overall agricultural resilience. Three Core Principles:

1. Minimum Soil Disturbance (No-Till):

This involves avoiding or minimizing tillage, which can disrupt soil structure, reduce water infiltration, and lead to erosion. Direct seeding into crop residues is a common practice in no-till systems.

2. Permanent Soil Cover:

Maintaining a layer of plant residue (dead or living) on the soil surface helps protect it from erosion, regulates soil temperature and moisture, and enhances soil organic matter.

3. Crop Diversification:

Rotating crops or intercropping with different species helps to break disease and pest cycles, improve nutrient cycling, and enhance overall biodiversity.

The carbon footprint in agriculture refers to the total greenhouse gas (GHG) emissions produced by agricultural activities. It encompasses emissions from various sources like crop and livestock production, land use changes, and the use of inputs like fertilizers and pesticides. Minimizing agriculture's carbon footprint is crucial for mitigating climate change and ensuring sustainable food production.

Reducing one's carbon footprint involves minimizing the amount of greenhouse gases released into the atmosphere. This can be achieved through various actions, including changing transportation habits, improving energy efficiency at home, adopting sustainable food practices, and reducing waste.

Conservation agriculture (CA) helps mitigate the carbon footprint:

1. Reducing Greenhouse Gas Emissions:

- **Reduced Tillage:** CA practices like no-till agriculture minimize soil disturbance, which reduces the release of carbon dioxide (CO2) from the soil. Tilling can release significant amounts of CO2 and also increase soil erosion, leading to further carbon loss.
- **Lower Energy Consumption:** By reducing the need for intensive tillage, CA reduces the amount of fuel and energy required for farming operations, thus lowering the overall carbon footprint.
- **Improved Nitrogen Use Efficiency (NUE):** Practices like crop rotation and cover cropping can improve NUE, reducing the need for synthetic nitrogen fertilizers. This is important because the production and use of nitrogen fertilizers are major sources of greenhouse gas emissions, particularly nitrous oxide (N2O).
- **Reduced Methane (CH4) Emissions:** In rice cultivation, practices like alternate wetting and drying (AWD) and residue management can reduce methane emissions, a potent greenhouse gas.

2. Enhancing Carbon Sequestration:

➢ **Soil Organic Carbon (SOC) Accumulation:** CA practices, especially those that increase biomass input and minimize soil disturbance, promote the accumulation of SOC in the soil. SOC acts as a carbon sink, storing atmospheric carbon and improving soil health.

➢ **Permanent Soil Cover:** Maintaining a permanent cover of vegetation, through cover crops or crop residues, helps protect the soil from erosion and enhances carbon sequestration.

➢ **Crop Diversification:** Crop rotation and diversification increase biomass production, leading to higher carbon inputs into the soil and improved soil health.

3. Synergistic Benefits:

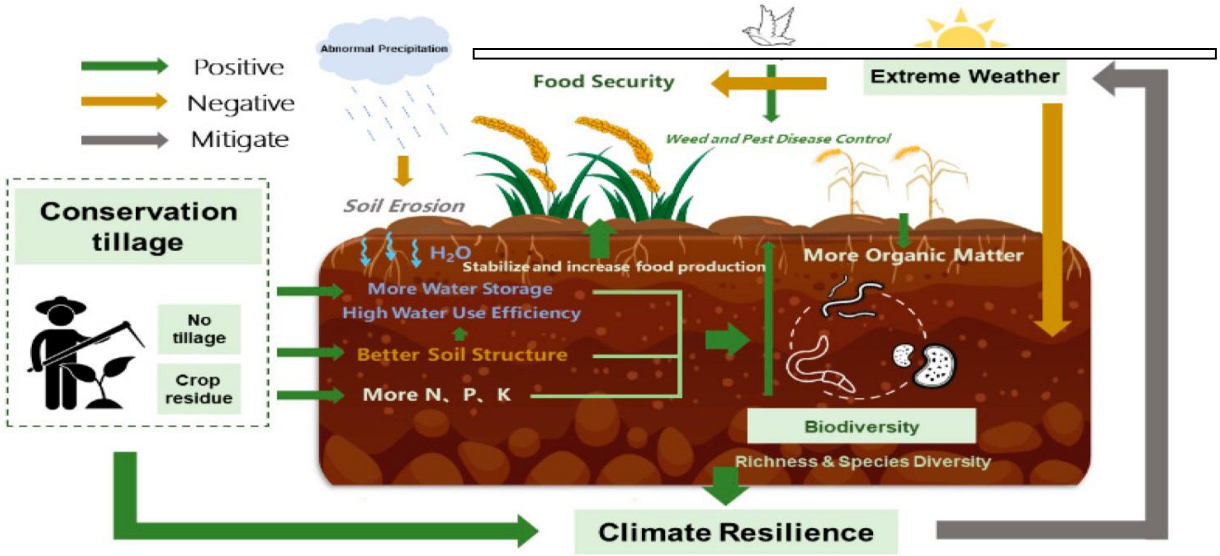
➢ **Improved Soil Health:** CA practices improve soil structure, water infiltration, and nutrient availability, leading to more resilient and productive agricultural systems.

➢ **Increased Crop Yields:** In many cases, CA has been shown to improve crop yields, further contributing to food security and reducing the need for land expansion.

➢ **Reduced Erosion:** By minimizing soil disturbance, CA helps reduce soil erosion, which not only prevents carbon loss but also protects water quality and prevents sedimentation of water bodies.

In conclusion, conservation agriculture offers a promising approach to mitigating the carbon footprint of agriculture by reducing greenhouse gas emissions and enhancing carbon sequestration. By adopting CA practices, farmers can contribute to a more sustainable and climate-resilient food system.

Carbon footprint varies among agricultural products due to species and farming practices. Diversified cropping systems can increase productivity while reducing the carbon footprint. Leguminous crops manifest a reduced carbon footprint via nitrogen & carbon. The resulting carbon footprint is governed by the arrangement of crops in a crop rotation system played a key. Cover crops pack a powerful punch for sustainability. They improve soil organic matter, promote nutrient cycling, can fix N from the air, prevent fields from being fallow, and protect against erosion. Sustainable agriculture practices support agriculture carbon footprint reduction. Crop rotations are one way to increase this diversity while reducing disease and pest pressure from years of repeated crop.



Source: Deng et al, Agronomy 2022, 12(7), 1575

Organic farming substantially aids in both mitigating and adjusting to climate change. This decrease could stem from a reduction in the utilization of mineral fertilizers and a rise in the organic matter content of the soil. Organic farming has several significant impacts on carbon emissions and soil health. In terms of carbon emissions, organic practices generally result in lower greenhouse gas outputs compared to conventional methods. This is partly because organic systems avoid synthetic fertilizers, which are associated with high nitrous oxide emissions—a potent greenhouse gas additionally, organic farming practices, such as the use of cover crops and reduced d tillage, enhance soil carbon sequestration, meaning that organic soils can store more carbon compared to conventional soils. Soil health benefits are also notable. Organic farming improves soil structure and increases soil organic matter, which enhances water retention and reduces soil erosion. Healthier soils contribute to higher resilience against extreme weather conditions, and the increased microbial activity in organic soils supports nutrient cycling and overall soil fertility. Consequently, organic farming not only helps in mitigating climate change through reduced carbon emissions but also promotes sustainable agricultural practices that improve long-term soil health and productivity.

Climate change, and mitigating greenhouse gas emissions from agriculture are crucial. Key sources of carbon footprints include rice fields, organic fertilizers, livestock, processing units, and machinery. Mitigation strategies like crop rotation, organic farming, biochar application, and summer fallowing offer effective ways to reduce emissions while promoting sustainability and enhancing soil health and biodiversity. By implementing these strategies and adopting sustainable practices, we can work towards a resilient future that balances environmental preservation with economic prosperity.

Summary:

Conservation agriculture (CA) can significantly mitigate the carbon footprint of agriculture by reducing greenhouse gas emissions and enhancing carbon sequestration in the soil. This is achieved through practices like minimum tillage, crop residue retention, and diversified crop rotations, which improve soil health and increase carbon storage. Conversion to CA significantly reduces GHGE from agricultural soils This work shows that transforming agricultural production systems to CA can significantly reduce GHGE from agriculture. As SOM builds up under these conditions, carbon can even be stored. This not only offsets the remaining emissions but makes the soil a net carbon sink. SOC accumulation starts in the first year of conversion to CA and stores. If this cropping system is maintained in perpetuity, emissions will continue to decrease due to reduced fertilizer and pesticide application rates, increasing the annual net sequestration. The hypothesis that CA has a smaller carbon footprint than tillage-based systems can thus be considered confirmed. However, it also became clear that no-till alone is not effective. Only the full application of the CA concept, i.e. integration of a permanent soil cover with living plants or a mulch layer, together with the greatest possible plant diversity, leads to SOC accumulation with increasing yields and co-benefits. In conclusion, conservation agriculture offers a holistic approach to farming that benefits both the environment and the farmer by reducing greenhouse gas emissions, enhancing carbon sequestration, and promoting sustainable and resilient agricultural systems.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Pollution and Microplastics: A Threat to Global Fisheries

I. Asraf Ali, P. Elakkanai, S. Rakesh, S. Mahamudul Hasan

TNJFU-Dr. M.G.R. Fisheries College and Research Institute, Thalainayeru - 614 712

Abstract:

Microplastic pollution is an emerging global environmental crisis impacting marine ecosystems and fisheries worldwide. Microplastics — tiny plastic particles smaller than 5 millimeters — originate from the breakdown of larger plastic debris, industrial effluents, and discarded fishing gear. Their pervasive presence in oceans and freshwater bodies poses significant risks to fish health, fisheries sustainability, and human food security. Fish ingest these microplastics, leading to physiological harm and contamination by toxic chemicals adsorbed onto the particles. This article explores the extent and implications of microplastic pollution on global fisheries, reviews the consequences for aquatic organisms and humans, and discusses potential mitigation strategies to safeguard aquatic biodiversity and fisheries resources.

Introduction:

Plastic pollution has become one of the most pressing environmental challenges of the 21st century. The versatility, durability, and low cost of plastics have led to their widespread use, but improper disposal and poor waste management have resulted in vast quantities of plastic waste entering marine and freshwater environments. According to Jambeck et al. (2015), an estimated 11 million metric tons of plastic waste enter the oceans annually. Over time, larger plastic debris fragments into microplastics — particles less than 5 mm in size — which have been detected from the ocean surface to deep-sea sediments worldwide.

Fisheries, a critical source of protein and economic livelihood for millions globally, are particularly vulnerable to microplastic pollution. More than 700 marine species, including many commercially important fish, have been found to ingest microplastics (Barboza et al., 2018). These particles cause physical injuries, chemical exposure, and can accumulate in tissues, affecting growth, reproduction, and survival. Moreover, microplastics can carry harmful chemical pollutants such as pesticides, heavy metals, and persistent organic pollutants (POPs), which accumulate along the food chain, ultimately posing risks to human consumers.

This article provides a comprehensive review of microplastic pollution's impact on fisheries, discusses implications for human health and economy, and suggests policy and management approaches to mitigate the threat.

The Nature and Sources of Microplastics:

Microplastics are classified into two broad types: primary and secondary. Primary microplastics are intentionally manufactured small plastic particles, such as microbeads used in personal care products and industrial abrasives. Secondary microplastics result from the fragmentation of larger plastic items like bottles, bags, and fishing nets due to environmental weathering, ultraviolet radiation, and mechanical forces.

Common sources of microplastics entering aquatic environments include:

- **Plastic litter breakdown** on beaches and coastlines
- **Runoff from urban areas** carrying plastic particles into rivers and seas
- **Wastewater discharge** containing synthetic fibers from washing clothes
- **Discarded fishing gear and aquaculture equipment** breaking down in the water
- **Industrial effluents** releasing plastic pellets or fragments

Because microplastics are small, lightweight, and chemically stable, they disperse widely and persist in water columns, sediments, and marine organisms. Their size allows them to be ingested by a variety of aquatic animals, including filter feeders, plankton, and fish.

Impact on Fish and Fisheries:

Microplastic ingestion has been documented in numerous fish species across different habitats, from coastal areas to the open ocean. Fish mistake microplastics for food or consume prey that have ingested plastics. Once ingested, these particles can cause physical obstruction in the digestive tract, internal injuries, and reduced nutrient absorption.

More importantly, microplastics can act as carriers for toxic chemicals. Studies indicate that substances like polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and endocrine-disrupting compounds adhere to microplastics and transfer to fish tissues upon ingestion (Wright et al., 2013). This chemical exposure can alter hormone levels, impair immune responses, and reduce reproductive success.

Research also shows that microplastic contamination can negatively influence fish behavior, including feeding and predator avoidance, further threatening their survival. The cumulative effects of physical and chemical stress from microplastics reduce fish populations and the productivity of fisheries.

In the Indian context, a study along the Visakhapatnam coast revealed microplastics in the digestive tracts of nearly all sampled fish and shellfish species, highlighting the severity of the problem in one of India's key fishing regions (Times of India, 2024). Such contamination threatens both the ecological balance of marine habitats and the safety of seafood consumed by local populations.

Human Health Concerns:

Microplastic contamination in seafood has raised growing concerns for human health. Barrows et al. (2021) reported that 99% of seafood samples worldwide contained microplastics, including shrimps, mussels, and small fish commonly consumed by humans. The consumption of contaminated seafood represents a direct pathway for microplastics and associated chemicals to enter the human body.

Although the full health impacts are still under scientific investigation, initial studies suggest microplastics may cause inflammation, oxidative stress, and cytotoxicity in human tissues. Microplastics have been found in human blood, lungs, and placentas, raising alarms about their potential long-term effects (Barrows et al., 2021). Additionally, chemicals adsorbed onto plastics, such as BPA and phthalates, are known endocrine disruptors linked to reproductive and developmental disorders.

Therefore, microplastic pollution threatens not only marine biodiversity but also food safety and public health, especially in communities heavily reliant on seafood.

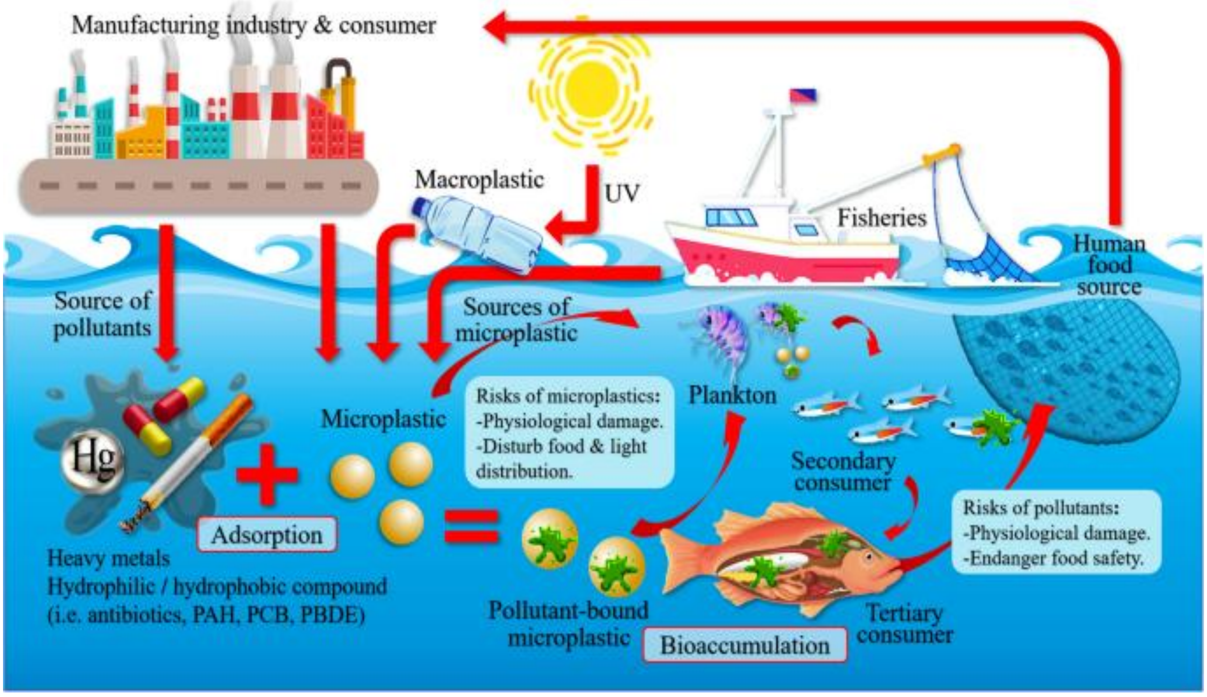


Fig 1: Microplastics in Ocean

Challenges	Impacts on Fisheries and Environment
Difficulty in managing plastic waste from land and sea sources	Physical harm to fish (blockages, injuries)
Lack of standardized methods for tracking microplastics in water and fish	Chemical toxicity from pollutants adsorbed on microplastics
Regulatory Gaps	Hormonal and immune system disruptions in aquatic species
Inadequate laws and enforcement on plastic use and disposal	Reduced fish growth, reproduction, and survival rates
Fisheries Gear Pollution	"Ghost fishing" and habitat degradation
Lost or discarded fishing nets contribute to marine litter	Decline in fish populations and catch quality
Human Health Uncertainty	Potential health risks from microplastic ingestion via seafood
Limited research on long-term effects on humans	Food safety concerns and potential economic losses
Economic Vulnerability	Loss of income and livelihoods for coastal communities
Dependence on fisheries makes communities vulnerable to stock declines	Reduced market value of contaminated seafood

Conclusion:

Microplastic pollution is an urgent environmental challenge with far-reaching consequences for global fisheries, aquatic ecosystems, and human health. The ingestion of microplastics by fish threatens their survival and reproduction, jeopardizing fish stocks and livelihoods dependent on fisheries. Moreover, contaminated seafood poses potential health risks to consumers, raising concerns about food safety worldwide.

Mitigating this threat demands coordinated global and local actions, including better waste management, stricter regulations, innovation in fishing gear, and heightened public engagement. Protecting fisheries from microplastic pollution is essential to ensuring food security, economic stability, and marine biodiversity for future generations.

References:

Jambeck, J. R., et al. (2015). Plastic waste inputs from land into the ocean. *Science*, 347(6223), 768–771. https://doi.org/10.1126/science.1260352

Barboza, L. G. A., et al. (2018). Marine microplastic debris: An emerging issue for food security, food safety and human health. *Marine Pollution Bulletin*, 133, 336–348. https://doi.org/10.1016/j.marpolbul.2018.05.047

Wright, S. L., Thompson, R. C., & Galloway, T. S. (2013). The physical impacts of microplastics on marine organisms: A review. *Marine Pollution Bulletin*, 62(12), 2453–2457. https://doi.org/10.1016/j.marpolbul.2013.09.041

Barrows, A. P. W., et al. (2021). Microplastic contamination in seafood: Global trends and human exposure potential. *Water Research*, 190, 116748. https://doi.org/10.1016/j.watres.2020.116748

Times of India. (2024). Study reveals widespread microplastic presence in seafood along Vizag coast. https://timesofindia.indiatimes.com/city/vijayawada/study-reveals-widespread-microplastic-presence-in-seafood-along-vizag-coast/articleshow/121629222.cms

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Innovations in Recirculating Aquaculture Systems (RAS) for Commercial Fish Production

I. Asraf Ali, P. Elakkanai, M. Daranni, J. Bovas Joel, S.J. Affin

TNJFU-Dr. M.G.R. Fisheries College and Research Institute, Thalainayeru - 614 712

Abstract

Recirculating Aquaculture Systems (RAS) have emerged as a transformative technology in commercial fish production, offering a sustainable alternative to traditional aquaculture and wild fisheries. These systems recirculate water through advanced filtration and treatment, enabling high-density fish farming with minimal environmental impact. Recent innovations in artificial intelligence (AI) monitoring, biofiltration, waste valorization, and renewable energy integration have significantly enhanced the efficiency, scalability, and sustainability of RAS. This article explores the latest technological advances, evaluates a large-scale commercial implementation, and discusses challenges and future prospects of RAS in global aquaculture.

Introduction

Global demand for seafood continues to rise amid declining wild fish stocks and increasing environmental concerns (FAO, 2022). RAS represents a cutting-edge approach to sustainable aquaculture by allowing fish production in land-based, controlled environments that recycle up to 99% of water and reduce dependency on natural water bodies. This system minimizes the risks of disease transmission, habitat degradation, and water pollution associated with open-net pen farming (NOAA Fisheries, 2023). As RAS technology evolves, integrating smart monitoring, efficient filtration, and energy-saving innovations, it is poised to become a key pillar of future seafood supply.

Innovations in RAS Technology

A major advancement in RAS is the application of AI-based water quality monitoring systems. Fan et al. (2024) developed a hybrid CNN-LSTM-attention neural network capable of accurately predicting nitrate levels (R^2=0.956), enabling operators to maintain optimal water conditions with minimal manual intervention. Such systems enhance fish health and feed efficiency by providing timely feedback and adjustments.

In filtration, while traditional biofilters converting ammonia to nitrate remain standard, new technologies such as encapsulated bacterial filters, membrane bioreactors, and electro-oxidation reactors are improving filtration efficiency, pathogen removal, and reducing maintenance (The Fish Site, 2023). These innovations contribute to more stable water quality and reduce downtime.

Waste management in RAS is evolving toward circular models. Microalgae bioreactors integrated with RAS remove up to 99% of nitrogen and phosphorus from effluents; producing biomass usable as biofertilizers or fish feed supplements (Sutherland et al., 2023). Additionally, hydrothermal liquefaction technologies convert solid waste into bio-oil and biogas, closing nutrient and energy loops within the system (Sun et al., 2024).

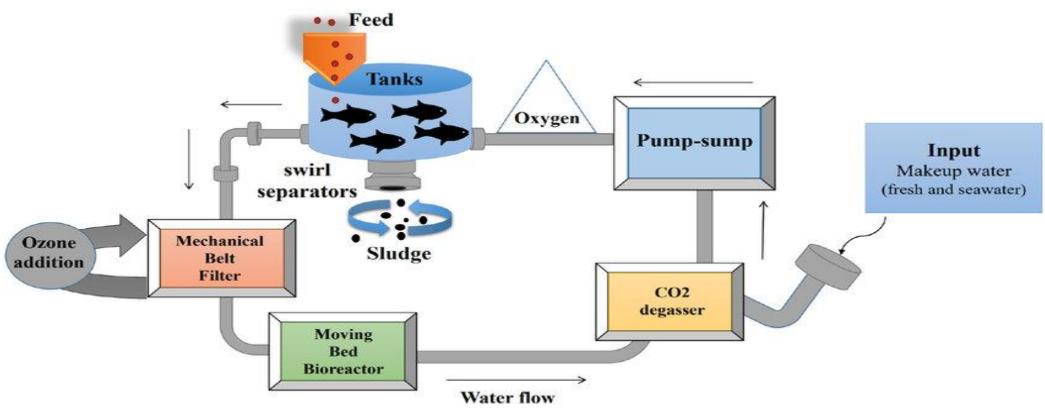


Fig 1: Recirculating Aquaculture System

Energy Efficiency and Sustainability

Energy use is a significant challenge for RAS, with consumption levels reaching 7,500 kWh per tonne of salmon produced (Ghamkhar et al., 2023). However, recent efforts focus on integrating renewable energy sources such as solar and wind, alongside energy-efficient pumps and heat recovery systems, achieving energy savings up to 40%. These developments reduce carbon footprints and operational costs, making RAS a more viable alternative to traditional methods.

Challenges and Future Directions

Despite these advances, RAS faces challenges including high upfront capital costs, complex technical requirements, and ongoing energy demand (Badiola, Mendiola, & Bostock, 2022). Overcoming these requires investment in training, subsidies, and supportive policies.

Future innovations will likely focus on fully automated smart farms utilizing digital twins, enhanced biofiltration technologies, and the combination of RAS with aquaponics and Integrated Multi-Trophic Aquaculture (IMTA). Additionally, policy frameworks encouraging carbon credits and green financing could accelerate adoption.

Conclusion

Recirculating Aquaculture Systems, empowered by AI, advanced filtration, waste recycling, and renewable energy, represent a sustainable future for commercial fish farming. Their ability to conserve water, improve biosecurity, and minimize environmental impacts positions them as a key strategy to meet increasing seafood demands responsibly. Large-scale projects like Huon Aquaculture's Whale Point highlight their potential at industrial scale.

References

Badiola, M., Mendiola, D., & Bostock, J. (2022). Recirculating aquaculture systems (RAS) analysis: Main issues on management and future challenges. *Aquacultural Engineering*, *69*, 60–70. https://doi.org/10.1016/j.aquaeng.2022.103088

Fan, Y., Liu, D., Zhao, Y., & Wang, R. (2024). A CNN-LSTM-attention model for water quality prediction in recirculating aquaculture systems. *arXiv preprint arXiv:2401.01491*. https://arxiv.org/abs/2401.01491

FAO. (2022). *The State of World Fisheries and Aquaculture 2022*. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/cc0461en/cc0461en.pdf

Ghamkhar, R., Zhang, L., & Lin, J. (2023). Energy and environmental assessment of aquaculture systems: A comparative LCA of land-based and net-pen salmon farming. *Sustainability*, *15*(7), 6108. https://doi.org/10.3390/su15076108

Herald Sun. (2024). Huon Aquaculture to invest $110m in new freshwater nursery. Retrieved from https://www.heraldsun.com.au/news/tasmania/huon-aquaculture-to-invest-110m-on-new-freshwater-nursery/news-story/c5fe1b1e518e582cb73105021e40bd48

NOAA Fisheries. (2023). Understanding Recirculating Aquaculture Systems. Retrieved from https://www.fisheries.noaa.gov/national/aquaculture/recirculating-aquaculture-systems

Sun, J., Li, X., Zhao, Y., & Wang, T. (2024). Valorization of aquaculture sludge via hydrothermal liquefaction: Bio-oil production and nutrient recovery. *Bioresource Technology*, *391*, 123456. https://doi.org/10.1016/j.biortech.2024.123456

Sutherland, D. L., Heubeck, S., & Craggs, R. J. (2023). Integration of microalgae in aquaculture RAS: Nutrient recovery and biomass production. *Algal Research*, *69*, 102998. https://doi.org/10.1016/j.algal.2023.102998

The Fish Site. (2023). Is it time to move beyond traditional biofilters in RAS? Retrieved from https://thefishsite.com/articles/is-it-time-to-go-beyond-traditional-biofilters-in-ras

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

FLORIGREENS: INTEGRATING MICROGREENS CULTIVATION IN FLORICULTURE

[1]UDITHYAN B AND [2]JEEVAA G

[1]Horticulture Graduate and [2]PG Scholar, Department of Floriculture and Landscape Architecture, Horticulture College and Research Institute, TNAU, Periyakulam

Corresponding author: jeevaa.pgfls2023@tnau.ac.in

Abstract:

Micro-greens are young seedlings harvested when two true leaves are emerged. They are highly rich in nutritional content than other vegetables. As an initiation of this innovative technology in floricultural crops, to extract the substitutional supply of nutrients equivalently to green leafy vegetables. In micro-green production technology, they can able to provide supplements 40 times greater than adult horticultural crops. Flowers from Asteraceae and Amaranthaceae family are most suitable for micro-greens production. Other flowers such as begonia, day lily, borage and pansy can also used for micro-green cultivation. Cultivation method ranges from substrate based cultivation, vertical farming and installation of LEDs in hydroponics and aeroponics to optimize its growth. Even though some minor constraints in cultivation of micro-greens due to high perishability nature, the demand of market is very high and improves the business potential and agri-research technology. The limited lifecycle and continuous harvest makes their movement in market actively both domestic and internationally. Future there will be soon hype reach demand for the micro-greens due to its protective and nutraceutical properties.

Introduction:

Today our world is going towards the path of leading a healthy life. On undergoing this well-being lifestyle, there should be intake of fruits and vegetables in our daily life. These foods are considered to be "**Protective Food**". Our daily recommendations for intake of vegetables given by ICMR (Indian Council of Medical Research) is 400g per day, as 125g of green leafy vegetables, 100g of roots and tuber crops and 250 g of other vegetables. Among this recommendation, leafy vegetables plays major role in shaping our balanced diet, as it is rich source of Fibers and Folic acid. For satisfying this dietary, there is an emerging trend in the advanced field of Horticulture known as Micro greens cultivation. It supplies required amount of minerals and fibers to our body. On considering these, integrating micro greens cultivation in floriculture helps in exploring the nutracsseuticals properties of various ornamental crops.

Micro-greens cultivation- An innovative horticulture:

Micro-greens are young edible seedlings harvested when two true leaves are emerged, typically 7 to 21 days after sowing. These are entirely differ from sprouts on their cultivation technology. As sprouts are grown in water without exposure to light and entire seedling is edible within 7 days, whereas Micro-greens are cultivated in various crops in controlled environment by utilizing of all sources plant growth factors. They are rich in antioxidants, minerals, vitamins sources of folic acid and fibers. They contains all vitamins, minerals and fibers 4 to 40 times more than adult vegetable crops. It is considered to be an innovation in the field of Horticulture. They has very fast growing crop cycle within 1-3 weeks and enables multiple harvests per month (Rouphael *et al.*,2021).

Flower crops used for micro-greens cultivation:

Edible flowers are blossoms that are safe for human consumption, used in cooking across many cultures of centuries. For example, rose for gulkhand preparation, crocus stigma for saffron etc.Here some of the edible flowers are listed as Begoina, Calendula, Day lilies, Sunflower, Nastrutium, Bachelor's button, Borage, Pansy, Chamomile and Chive, Mustard, Cilantro, Nigella, Fennel etc. are few edible aromatic herbal flowers (Park *et al.*, 2022).

Table 1: Nutritional properties various flower crops used for micro-greens cultivation (Purohit *et al.*,2021)

PURPOSE	CROPS USED	NUTRITIONAL PROPERTY
Salads & garnishes	Nasturtium	Anthocyanin, vitamin C, phenolic acids, anti-inflammatory property
	Pansy	High flavonoids, carotenoids, vitamins A & C
	Calendula	High lutein/carotenoids, phenolics
	Borage	Potassium, iron , vitamin A and C
	Bachelor's button	Vitamin C, Folates and Calcium
Drinks & ice cubes	Freeze borage	antioxidants, vitamins A, C, and Folate), and minerals like potassium, magnesium, and iron
	Lavender	Vitamin A, iron calcium
	Chamomile	Bio-active compounds such as apigenin and flavonoids
	Hibiscus	Vitamin C, calcium, iron, and potassium, anthocyanins and polyphenols
Desserts & baking	Rose	Flavonoids, anthocyanins, phenolic acids, antioxidants
	Sunflower	Sources of good fat such as PUFA(Poly Unsaturated Fatty acids)
Savory dishes	Squash blossoms	high amounts of vitamin B6 and fiber
	Chive blossoms	vitamins K, A, and C
	Chrysanthemum	dietary fiber, potassium, calcium, iron, and vitamins A, B, C, and K, along with powerful antioxidants like flavonoids and carotenoids (lutein and zeaxanthin)

Scope of cultivation of flowers as micro-greens:

a) **Nutritional property**

Micro-greens are rich in vitamins, minerals, fibers and antioxidants. Especially flower crops belong to Amaranthaceae and Asteraceae family is widely cultivated for micro-greens purpose. They are multiple times rich in nutrients than adult vegetable crops.

b) **Utilization of space**

Cultivation of micro-greens in large scale can even done in smaller areas and under-utilized space in our cultivating areas. Even they can also cultivated in our terrace garden.

c) **Year round cultivation**

As these crops can be cultivated in wider range of climatic conditions. So the yield can be seen throughout the year. For example, Zinna and Gomphrena are summer crops while Chrysanthemum and celosia are winter crops, so the production of micro-greens is feasible over a year.

d) **Economic development**

Micro-greens are considered to be important source of diet in today scenario. So the marketable price of the micro-greens is more compared to other leafy vegetables. Proper packaging technology can improve its grade and quality. Along with greens production, there is another possibility of production of commercial flowers.

e) **Labour intensive**

Since these require minimum amount of area, the household people is enough to maintain and harvest the produce and easy for transportation.

Cultivation technology:

Commercially, micro-greens are cultivated in controlled environment especially in polyhouses, but they can also grow in ambient conditions with most care to get quality greens materials. There are many methods are followed in cultivation of micro-greens based on space and availability of raw materials.

i. **Soilless substrate based farming**

It is most convenient method for cultivating of greens for non-commercial method especially for home gardening. Peat moss, coconut coir, paddy straw, typha grass, or other porous inert materials are used for cultivation of micro-greens. Small reusable grow trays are used for cultivation as containers (Teng *et al.*,2023).

Figure 1: soilless substrate cultivation of micro-greens
(a) virtual image micro-greens cultivation
(b) visual representation micro-greens cultivation

ii. **Vertical gardening technology**

It is considered to be soilless cultivation technique, where all nutrients for growth of micro-greens is given through roots directly via nutrient solution by film technology. It includes aquaponics, hydroponics and aeroponics techniques (Singh, 2023).

Figure 2: Containers used for micro-greens cultivation in vertical garden technology

Figure 3: Micro-greens in vertical farming

iii. **Artificial lighting technology**

It is the most costliest technology and highly beneficial technology in cultivation if micro-greens. LEDs (Light Emitting Diode) are used for growing of micro-greens, which fastens the growth of micro-greens than optimum environment without reducing the nutritional properties of the micro-greens. It is highly suitable for indoor cultivation of micro-greens (Appolloni *et al.*,2022).

Figure 4: LED technology in micro-greens cultivation

Constraints in microgreens cultivation :

- Highly perishable
- Cost of installation is high
- Constant maintenance should required
- Lack of packaging technology
- Pest and disease surveillance is difficult

Future prospects of Microgreens cultivation in flower crops:

- Growing Demand for Functional and Nutritional Foods
- Helps in urban and Indoor Farming Opportunities
- Improves research and Innovation
- Helps in growth of export and Agri-Tourism Potential
- Improving business potential and market stability
- Provides sustainable farming technology

References :

Appolloni, E., Pennisi, G., Zauli, I., Carotti, L., Paucek, I., Quaini, S., ... & Gianquinto, G. (2022). Beyond vegetables: effects of indoor LED light on specialized metabolite biosynthesis in medicinal and aromatic plants, edible flowers, and microgreens. *Journal of the Science of Food and Agriculture*, *102*(2), 472-487.

Park, Y., Gómez, C., & Runkle, E. S. (2022). Indoor production of ornamental seedlings, vegetable transplants, and microgreens. In *Plant factory basics, applications and advances* (pp. 351-375). Academic Press.

Purohit, S. R., Rana, S. S., Idrishi, R., Sharma, V., & Ghosh, P. (2021). A review on nutritional, bioactive, toxicological properties and preservation of edible flowers. *Future Foods*, *4*, 100078.

Rouphael, Y., Colla, G., & De Pascale, S. (2021). Sprouts, microgreens and edible flowers as novel functional foods. *Agronomy*, *11*(12), 2568.

Singh, B. (2023). New systems of vegetable production: Protected cultivation, hydroponics, aeroponics, vertical, organic, microgreens. In *Vegetables for Nutrition and Entrepreneurship* (pp. 31-56). Singapore: Springer Nature Singapore.

Teng, Z., Luo, Y., Pearlstein, D. J., Wheeler, R. M., Johnson, C. M., Wang, Q., & Fonseca, J. M. (2023). Microgreens for home, commercial, and space farming: a comprehensive update of the most recent developments. *Annual review of food science and technology*, *14*(1), 539-562.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Broodstock Nutrition: A Key to Sustainable Aquaculture and Seed Production

Dr. Gyandeep Gupta, Dr. D.K. Shrivastva, Dr Ajit Singh Vats and Dr Ram Lakhan Singh
Krishi Vigyan Kendra, Mankapur, Gonda-II
Acharya Narendra Deva University Of Agriculture And Technology, Kumarganj, Ayodhya

Broodstock nutrition is one of the most essential components for achieving sustainable aquaculture production. A key requirement for the successful expansion of aquaculture is the effective management of sexual maturation and spawning, along with the ability to produce large quantities of high-quality seed. Scientific studies have consistently shown that enhancing broodstock nutrition and feeding practices leads not only to improved egg and sperm quality, but also to a significant increase in seed yield. The development of optimal broodstock management strategies relies on a comprehensive understanding of the nutritional and environmental requirements of fish reared under captive conditions.

Among the major nutritional factors that influence fish growth, gonadal development, and reproductive performance are proteins, lipids, minerals, vitamins, and carotenoids etc. Providing a well-balanced diet enriched with these macro- and micronutrients enhances fertility, supports better hatching success, and improves the survival rate of larvae. The quality of eggs produced by broodstock is a critical determinant of the health, growth, development, and eventual reproductive success of the resulting larvae. Since egg quality directly depends on the levels of essential nutrients deposited by the female fish during oogenesis, it becomes imperative to optimize the broodstock diet to ensure the successful survival, development, and future reproductive capacity of fish larvae.

Importance of Protein in broodstock diets

Protein is an essential dietary component in broodstock feed, playing a vital role in providing both essential and non-essential amino acids. It serves as a readily available energy source, especially when other energy sources are insufficient, and supports the synthesis of new tissues, hormones, enzymes, and antibodies. In broodstock, protein is also utilized as a key energy source during the reproductive process, contributing to male aggressive behavior necessary for mating, territory defense, and oral egg incubation in certain species.

The quality and quantity of protein required in the broodstock diet depend on several factors, including water temperature, salinity, age, sex, amino acid profile, stage of maturation, spawning period, feeding frequency, and the overall dietary energy level. Meeting the optimal protein requirement in broodstock feed formulation is crucial to avoid poor reproductive performance, stunted growth, and body weight loss.

Protein plays a direct role in egg development, spawning, follicle formation, ovarian tissue production, and embryonic growth and development. The effects of dietary crude protein levels on fertility and reproductive output vary across different fish species, highlighting the need for species-specific protein formulation in broodstock nutrition.

Recommended Dietary Protein Levels for Broodstock Fish

Species	Protein Requirement (%)	Reference
Labeo rohita (rohu)	30–35%	Das et al., 2006
Catla catla	35%	Swain et al., 2004
Clarias batrachus / magur	35–40%	Aliyu-Paiko et al., 2010
Oreochromis niloticus (tilapia)	30–36%	Rana, 1990; El-Sayed & Kawanna, 2008
Salmonids (e.g., trout, salmon)	42–50%	Izquierdo et al., 2001
Seabass, Seabream (marine)	45–55%	Izquierdo et al., 2001; Bobe & Labbé, 2010

Amino acid

A well-balanced diet for broodstock fish, enriched with essential amino acids, plays a vital role in enhancing reproductive performance. According to Mazid et al. (1978), ten essential amino acids are necessary for the normal growth and development of tilapia: arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. A deficiency in any of these amino acids can impair protein synthesis, hinder growth, and disrupt metabolic functions, ultimately leading to weight loss and reduced reproductive efficiency. Certain amino acids, such as arginine and glutamate, are crucial in regulating hepatic glucose and lipid metabolism. Moreover, amino acids like glutamate, glycine, and tyrosine are involved in stimulating the release of pituitary hormones, which influence both food intake and reproductive behaviors in fish.

Essential Amino Acids and Their Role in Fish Reproduction

Amino Acid	Reproductive Role in Fish	References
Arginine	Stimulates nitric oxide (NO) production → improves gonadal blood flow and sperm motility	Kaushik & Seiliez (2010); NRC (2011)
Histidine	Supports enzyme activity in gonadal tissues and contributes to antioxidant defense in ovaries	NRC (2011); Izquierdo et al. (2001)
Isoleucine	Involved in protein synthesis during testis and ovary development	NRC (2011)
Leucine	Aids in ovarian growth, follicle maturation, and muscle development in developing embryos	Kaushik & Seiliez (2010); NRC (2011)
Lysine	Crucial for vitellogenin and yolk protein synthesis, improves egg quality and fertilization rate	Izquierdo et al. (2001); Aliyu-Paiko et al. (2010); NRC (2011)
Methionine	Donates methyl groups for hormone synthesis; essential for egg protein and embryo development	NRC (2011); Kaushik & Seiliez (2010); Das et al. (2006)
Phenylalanine	Precursor for tyrosine → dopamine, influences GnRH release and reproductive hormone regulation	Zohar et al. (1995); NRC (2011)
Threonine	Supports mucosal immunity in gonads, contributes to gonad tissue formation	Kaushik & Seiliez (2010); NRC (2011)
Tryptophan	Precursor to serotonin → regulates GnRH and LH secretion, reduces stress during spawning	Singh & Joy (2009); NRC (2011); Izquierdo et al. (2001)
Valine	Important for cell division and protein turnover in rapidly growing gonadal cells	NRC (2011); Kaushik & Seiliez (2010)

Role of Lipids and Essential Fatty Acids (EFAs) in Broodstock Nutrition

Lipids serve as a major energy source for somatic growth in most fish species. Beyond their energy-providing role, lipids are a vital source of essential fatty acids (EFAs), which are crucial for the formation of cell membranes and are indispensable for normal larval development. For the successful production of strong and healthy larvae, it is essential that broodstock diets supply the correct types and adequate levels of EFAs—particularly long-chain polyunsaturated fatty acids (LC-PUFAs).

In female broodstock, sufficient intake of energy-rich fatty acids and EFAs is necessary to not only support their own growth and metabolic demands but also to ensure the provision of LC-PUFAs needed for proper larval development. Research has shown that the lipid and fatty acid composition of broodstock diets significantly influences reproductive efficiency and the survival rate of progeny. Interestingly, many fish species are capable of incorporating unsaturated fatty acids from their diet directly into their eggs—even during the spawning season. Lipids are among the most abundant components of fish egg yolks and are fundamentally involved in various reproductive processes including oocyte development, egg production, and embryo development. During fish maturation and reproduction, lipids are mobilized from maternal reserves and transferred into oocytes, where they are stored in the yolk and later utilized by the developing embryos. Lipids contribute to membrane structure and function, and they represent the primary energy source for the growing embryo. The lipid content in muscle tissue also acts as a reservoir for the ovaries, and it is often used as an indicator of reproductive potential or success.

The ability of a species to accumulate somatic lipid reserves during the reproductive cycle varies; however, when the body lipid content is insufficient, reproductive output may be compromised due to energy limitations. This emphasizes the importance of providing a consistent and balanced energy supply throughout the reproductive cycle. Typically, a minimum of 10% dietary lipid is necessary to optimize protein utilization. However, feeding excess lipids can interfere with the intake of other essential nutrients, thus affecting overall reproductive performance. Numerous studies have highlighted the direct relationship between the fatty acid profile of broodstock diets and the fatty acid composition of eggs and fry, indicating the need for carefully formulated lipid profiles. Deficiencies in essential fatty acids can negatively impact fish oogenesis, leading to poor reproductive outcomes. The fatty acid requirements of fish vary with species and environmental temperature. For example: Warm-water fish generally require n-6 PUFAs, or a combination of n-3 and n-6 fatty acids. Cold-water fish primarily benefit from n-3 fatty acids. The most biologically active forms of these fatty acids are: Arachidonic acid (ARA) – a key n-6 fatty acid, Eicosapentaenoic acid (EPA) and Docosahexaenoic acid (DHA) – key n-3 fatty acids

In freshwater species, EFA needs can often be met by the dietary inclusion of shorter-chain precursors such as linoleic acid (n-6) and linolenic acid (n-3). However, providing the diet with pre-formed bioactive highly unsaturated fatty acids (HUFA) like EPA and DHA may lead to better reproductive and developmental performance. Among all nutritional factors, the dietary content of essential fatty acids has been consistently identified as one of the most influential determinants of fish reproductive success.

Importance of Lipid in Broodstock Nutrition

Function	Reproductive Importance
Energy source	Lipids provide energy for gametogenesis and spawning activities
Essential Fatty Acids (EFAs)	EFAs like DHA, EPA, and ARA are crucial for egg quality, fertility, and larval survival
Steroid hormone precursor	Cholesterol from lipids is a precursor of sex hormones (estrogen, testosterone)
Yolk and vitellogenin synthesis	Lipids form a major part of yolk, supplying nutrients to the developing embryo
Cell membrane structure	Phospholipids are essential for oocyte membrane integrity and fertilization

Recommended Lipid Levels in Broodstock Fish Diets

Fish Species	Lipid Requirement (% of Diet)	Remarks	References
Labeo rohita (Rohu)	8–10%	Enhances fecundity and egg quality	Mohanty, 1999; Das et al., 2006
Catla catla	8–10%	Supports vitellogenesis and GSI improvement	Swain et al., 2004
Clarias batrachus / magur	9–12%	Improves spawning performance and milt quality	Aliyu-Paiko et al., 2010
Tilapia (*Oreochromis spp*.)	7–10%	Improves fertilization rate and larval quality	El-Sayed, 2006
Rainbow trout / Salmon	12–20%	High lipid improves egg size, DHA/EPA-rich egg yolk	Izquierdo et al., 2001
Marine broodstock (seabass)	10–18%	Require DHA, EPA, ARA for egg viability and hatching success	Sargent et al., 2002; NRC, 2011

Role of Minerals in Broodstock Nutrition

Minerals are vital micronutrients in the diets of fish broodstock, essential for supporting a wide range of physiological functions related to reproduction. They play a crucial role in hormonal regulation, enzyme activation, skeletal formation, reproductive tissue development, and immune system function. Adequate mineral supplementation in broodstock diets contributes significantly to improving gamete quality, increasing fertilization and hatching success, and ensuring the healthy development of larvae. Balanced mineral nutrition is, therefore, a key component in achieving optimal reproductive performance in cultured fish species.

Key Minerals in Broodstock Reproduction

Mineral	Functions in Reproduction
Calcium (Ca)	Supports **vitellogenesis**, eggshell formation, muscle contraction in spawning
Phosphorus (P)	Crucial for **energy metabolism (ATP)**, bone development, and **oocyte maturation**
Zinc (Zn)	Vital for **hormone synthesis**, **enzyme activation**, improves **sperm quality** and **ovarian development**
Iron (Fe)	Essential for **oxygen transport** in developing embryos, supports **egg viability**
Manganese (Mn)	Required for **gonadal development** and **enzyme function** in gamete production
Magnesium (Mg)	Involved in **hormone regulation**, energy production, and **reproductive enzyme activity**
Selenium (Se)	Important antioxidant, protects **oocytes and sperm** from oxidative damage
Copper (Cu)	Supports **maturation of eggs**, and plays a role in **hormonal functions**

Effects of Mineral Supplementation on Broodstock

Mineral	Effects on Reproduction	References
Zinc	Improves **oocyte development**, increases **fertilization rate**, and enhances **hatchability**	Lin et al., 2008; NRC, 2011
Calcium & Phosphorus	Essential for **eggshell formation**, **bone growth** in embryos	NRC, 2011; Lall, 2002
Iron	Prevents **embryonic anemia**, increases **larval survival**	NRC, 2011
Magnesium	Supports **egg maturation** and **sperm motility**	Roy & Lall, 2006
Selenium	Antioxidant role, enhances **egg quality**, **fertility** and **immune protection** of eggs	Wang et al., 2007
Manganese	Stimulates **reproductive hormone enzymes** and **gonadal activity**	Lall, 2002
Copper	Aids in **vitellogenesis** and **ovarian steroidogenesis**	Sat

Role of Vitamins in Broodstock Nutrition

Vitamins are essential micronutrients that play pivotal roles in broodstock health, gametogenesis, hormone synthesis, embryonic development, and immune function. Adequate vitamin supplementation significantly improves reproductive performance, egg quality, fertility, and larval survival. Among these, fat-soluble vitamins A and E are particularly important, as they are efficiently transferred from the maternal diet to developing eggs. Vitamin C is also critical, involved in numerous metabolic processes such as collagen formation (for tissue repair), cell membrane protection, metal absorption, and detoxification of xenobiotics. Additionally, it functions as a potent reducing agent, acting both within and between cells. Research has demonstrated that dietary inclusion of vitamin C (ascorbic acid) enhances fish health and reproductive efficiency. However, due to its oxidation-prone and time-sensitive nature, a diverse and stable source of vitamin C, such as L-ascorbic-2-phosphate, is commonly used in formulated feeds. In salmonids, ascorbic acid has shown beneficial effects on steroidogenesis and vitellogenesis, crucial processes for successful reproduction.

Vitamins C and E, known for their antioxidant properties, protect sperm cells during spermatogenesis and fertilization by reducing the risk of lipid peroxidation, which can impair sperm motility. The level of vitamin C in seminal fluid reflects dietary intake and is especially important in the later stages of the spawning cycle, where deficiency has been linked to reduced sperm concentration and motility.

Vitamin B6 plays a role in the synthesis of steroid hormones and folic acid, both of which are essential for cell division and DNA/RNA synthesis. A deficiency in B6 can result in impaired cell division, negatively impacting egg development and hatchability. Vitamin E deficiency has been associated with poor reproductive outcomes, including underdeveloped gonads, reduced hatching rates, and lower offspring survival, as observed in various vertebrates.

Key Roles of Vitamins in Fish Reproduction

Vitamin	Function in Reproduction
Vitamin A (Retinol)	Essential for **gonadal development**, oocyte maturation, and embryo differentiation
Vitamin D	Regulates **calcium metabolism**, important for **ovary function and milt quality**
Vitamin E (α-Tocopherol)	Powerful **antioxidant** protecting oocytes/sperm from oxidative stress; improves egg viability
Vitamin C (Ascorbic Acid)	Enhances **fertility**, reduces deformities, improves **egg adhesion and hatching**
B-complex vitamins	Cofactors in **energy metabolism**, steroidogenesis, and nervous system development in embryos

Effects of Vitamin Supplementation on Broodstock Fish

Vitamin	Observed Effects on Broodstock	References
Vitamin A	Enhances **fecundity**, **ovarian growth**, and **hatchability**; deficiency leads to skeletal deformities in larvae	Cahu et al., 2003; Mazorra et al., 2003
Vitamin D	Improves **reproductive hormone regulation**, **gonadal development**, and **sperm motility**	Kaushik, 1998; NRC, 2011
Vitamin E	Prevents **lipid peroxidation** in eggs and sperm, increases **egg survival**, improves GSI	Izquierdo et al., 2001; Lin & Shiau, 2005
Vitamin C	Essential for **collagen formation**, **gonadal maturation**, enhances **immune protection of brooders** and eggs	Dabrowski, 1990; Lim & Lovell, 1978
Vitamin B12, B6, B1, etc.	Improve **hormonal balance**, **reproductive enzyme activity**, and **larval neural development**	NRC, 2011; Cowey & Sargent, 1972

Role of Carotenoids in Broodstock Nutrition

Carotenoids are naturally synthesized by plants, phytoplankton (microalgae), zooplankton, and crustaceans, making the availability of natural or live food sources crucial for their inclusion in the diet. In aquaculture ponds, the presence of these organisms directly influences skin pigmentation in fish through dietary carotenoid intake. The most common carotenoids found in freshwater systems include astaxanthin, zeaxanthin, xanthophylls, lutein, β-carotene, taraxanthin, and tunaxanthin.

The inclusion of carotenoids in broodstock diets has been linked to the healthy development of embryos and larvae, emphasizing their nutritional significance beyond pigmentation. Carotenoids are among the most important pigment groups in fish and serve a wide range of biological functions. These include:

- Protection against harmful light (UV radiation)
- Acting as provitamin A sources
- Enhancing spermatozoa chemotaxis (guidance of sperm to the egg)
- Possessing strong antioxidant properties, such as singlet oxygen quenching

Due to these functions, carotenoids contribute significantly to reproductive health, larval development, and overall physiological well-being in broodstock.

Compiled list of commercial and specialized fish feeds developed by various ICAR institutes in India:

Institute	Feed Name	Purpose/Use	Key Features
ICAR-CIFA, Bhubaneswar	CIFABROOD™	Broodstock feed for carps	Enhances egg/milt production, hatchling survival
	CIFACORN™	Starter feed for carp hatchlings	Micro-pellets for early growth of fry
	CIFAMAGUR™	Broodstock feed for *Clarias magur*	Promotes gonadal development and reproductive success
ICAR-CIFE, Mumbai	CIFACARB™	Grower feed for carps	Balanced nutrition for optimal carp growth
	CIFACLIN™	Fish health feed	Boosts immune function, prevents diseases
	CIFASTARTER™	Starter feed for fish larvae	Nutrient-dense feed for early development
ICAR-CIFRI, Barrackpore	CIFRI BROOD™	Broodstock feed for reservoir fisheries	Improves reproductive performance under reservoir conditions
ICAR-CIFT, Kochi	Fish Waste-Based Aquafeed	Low-cost fish feed using waste	Uses heads, viscera, bones; nutrient-rich, cost-effective
	On-Site Feed Production Line	Processing unit for decentralized feed production	500 kg/day, suitable for rural/micro-industries
	Shrimp Shell-Based Pet Feed Supplement	Ornamental and pet fish supplement	High PUFA, protein, carotenoids; adaptable for aquafeed and pet food markets

References

Khan, M. A., Jafri, A. K., & Chadha, N. K. (2005). Effects of varying dietary protein levels on growth, reproductive performance, body and egg composition of rohu (Labeo rohita) broodstock.Aquaculture, 246(1–4), 271–281.https://doi.org/10.1016/j.aquaculture.2005.01.009

Das, P. C., Ayyappan, S., & Jena, J. K. (2006).Effect of different dietary protein levels on growth, survival, and feed conversion of rohu (Labeo rohita) fry.Indian Journal of Fisheries, 53(3), 283–287.

Swain, P., Nayak, S. K., Nanda, P. K., & Dash, S. (2004).Effect of dietary protein on reproductive performance and egg quality of Indian major carp Catla catla.Journal of Applied Aquaculture, 16(1–2), 103–115.https://doi.org/10.1300/J028v16n01_08

Aliyu-Paiko, M., Hashim, R., & Aliyu-Paiko, M. (2010).Effect of dietary protein levels on reproductive performance and histological changes of gonads in catfish (Clarias gariepinus) broodstock.Journal of Fisheries and Aquatic Science, 5(5), 375–382.https://doi.org/10.3923/jfas.2010.375.382

Gunasekera, R. M., De Silva, S. S., & Collins, R. A. (1996).Reproductive performance, egg and larval quality of Oreochromis niloticus fed diets differing in essential fatty acid content.Aquaculture, 146(3–4), 303–314.https://doi.org/10.1016/S0044-8486(96)01381-1

El-Sayed, A. F. M., & Kawanna, M. (2008).Effects of photoperiod on the performance of Nile tilapia (Oreochromis niloticus) larvae reared in a recirculating system.Aquacultural Engineering, 38(1), 61–67.https://doi.org/10.1016/j.aquaeng.2007.11.003

Izquierdo, M. S., Fernández-Palacios, H., & Tacon, A. G. J. (2001).Effect of broodstock nutrition on reproductive performance of fish.Aquaculture, 197(1–4), 25–42.https://doi.org/10.1016/S0044-8486(01)00581-6

Bobe, J., & Labbé, C. (2010).Egg and sperm quality in fish.General and Comparative Endocrinology, 165(3), 535–548.https://doi.org/10.1016/j.ygcen.2009.02.011

National Research Council (NRC). (2011). Nutrient Requirements of Fish and Shrimp. Washington, DC: National Academies Press. https://doi.org/10.17226/13039

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Foliage Beyond Flowers: A Study on the Emerging Importance of Cut Greens

Swapnil Bharti[1], Paramveer Singh[1], Meenu Kumari[1] and Vikas Chandra[2]

[1]Assistant Professor-cum-Jr. Scientist, (Floriculture & Landscaping), Bihar Agricultural University, Sabour, Bhagalpur
[2]Assistant Professor-cum-Jr. Scientist, (Fruit & Fruit Technology), Bihar Agricultural University, Sabour, Bhagalpur

Abstract

The floriculture sector is experiencing rapid expansion, propelled by escalating demand for aesthetically appealing floral products across domestic and international markets. In addition to cut flowers, cut foliage, commonly referred to as *ornamental greens* plays an essential role in floral design by contributing structural volume, textural complexity, and visual contrast. These plant materials are prized for their morphological uniformity, vivid pigmentation, physiological freshness, high tolerance to desiccation, and extended post-harvest longevity. Predominant taxa utilized include members of the genera *Nephrolepis* (ferns), *Areca* (palms), *Eucalyptus*, and *Monstera*, frequently incorporated into bouquets, wreaths, and ornamental installations. Optimal cultivation of cut foliage requires specific agro-ecological conditions, including 50–75% shade, high relative humidity, well-aerated, slightly acidic soils and moderate temperatures. Species-specific propagation is achieved via seeds, stem and leaf cuttings, division, air layering, and spore germination. From an economic standpoint, cut foliage production offers high benefit-cost ratios, with low capital and input requirements, rendering it highly viable for smallholder and marginal farmers. It also supports rural employment, particularly among women, through opportunities in processing and value addition. In floral arrangement, foliage is classified into line, mass, filler, and form types, each contributing to spatial orientation and design balance. The cut foliage industry demonstrates significant export potential especially to markets in Europe, North America, and Japan, while also fulfilling expanding domestic demand driven by urbanization and interior landscaping trends. When integrated with optimized cultivation and post-harvest protocols, this sector offers a resilient and economically sustainable avenue within modern floriculture.

Keywords: Cut foliage, Export potential, Floriculture industry, Indoor plants

Introduction

Floriculture offers immense potential and has become an integral part of modern lifestyles. The industry has evolved into a commercial business venture with significant market value and promising opportunities. Floriculture is rapidly emerging as a lucrative segment within the agriculture sector, experiencing steady growth worldwide and proving to be a promising agricultural activity, particularly in developing countries. With rapidly evolving trends and a continuous demand for innovative products in both domestic and major international flower markets, flower growers must respond quickly. Consumptions of flowers in India is growing at a rate of up to 30% per annum, driven by numerous festivals, rising modernization, and increasing per capita income—positioning the country as a potential floral superpower. Additionally, the global import and export of floriculture products continue to rise each year. The production of cut flowers has a great potential to increase the livelihood of both small and marginal farmers with a condition that the selection of the varieties should be as per the certain criteria such as vibrant and novel colors, sturdy stems, higher yield and quality, disease and pests' resistance, resistance to lodging and vase life. Along with the flowers the demand for cut greens is also increasing tremendously. Cut greens or cut foliage is a vegetation used in large quantities as a source of decoration on its own or in association with flowers in bouquets. Evergreen plants featuring green, silver, or variegated foliage are commonly used, along with the species bearing berries that are also gaining popularity. Cut foliages are those which stay green for long time, retain their appearance and do not shed leaves or berries. The most popularly used cut foliages in flower arrangements are asparagus, ferns, thuja, cupressus, eucalyptus because of its year-round availability and longer vase life. India is endowed with various agro-climatic conditions suitable for growing a large variety of foliage plants. Such as abundant sunshine throughout the year, high amount of diversity in indigenous flora, a wide range of soil type, low labour and investment cost. Therefore, the commercial cultivation of this cut foliage can be helpful in improving the livelihood of the farmers.

What are cut foliage:

Cut foliage, also known as ornamental foliage, cut greens or florist's greens, with or without decorative fruits, seed pods etc. that can be used as fillers and is valued for its attractive form, vibrant color, and fresh appearance of leaves and stems. It typically features a substantial texture, well-formed sprays, and high resistance to wilting, making it long-lasting in floral arrangements. These qualities make cut foliage a charming addition to floral designs, bouquets, and wreaths.

Plants cultivated for the production of cut greens must exhibit specific quality characteristics.

- Foliage must be healthy and fresh looking
- Resistance to insect pest and disease
- Quick growing and respond to regular cutting
- Long vase life,
- Ability to withstand long transportation and storage
- Should be without undesirable characteristics like thorns, unpleasant odour or excessive exudates
- Should provide mass effect in background
- Novel colour of foliage
- Provides foliage ready to cut in less time
- Healthy vigour for regular cutting
- Production of vertical or horizontal growth
- Plant material should not have undesirable characteristics

Plants that can be used as cut foliage or cut greens are:

Category	**Examples**
Trees	*Grevillea, Callistemon, Thuja, Eucalyptus, Salix*
Shrubs	*Aralia, Acalypha, Hedera helix, Muraya,* Cordyline, Aralina, Duranta
Creepers	*Monstera, Asparagus,* Scindaspus, Philodendron
Pot plants	*Dracaena, Aspidistra, Ruscus*
Annuals	Coleus, Cosmos
Herbaceous perennials	Golden rod, Anthurium, Areca
Grasses	*Typha, Arundo,* Emu grass, Fountain grass, Beargrass, Pampas grass
Ferns	*Asparagus, Rumohra, Nephrolepis,* Leather leaf fern, Sharon fern
Palms	*Areca, Cycas revoluta, Livistonia, Rhaphis*

Nephrolepis cordifolia

Pteris vittata

Nephrolepis exaltata

✓ Varieties like *Nephrolepis exaltata* (Boston fern), *Nephrolepis biserrata furcans* (Giant sword fern) *Nephrolepis cordifolia 'Duffii,' (and 'Sprengeri' compacta* Fish bone fern, ladder fern or Tuberous sword fern are well-suited as cut foliage plants, while *Pteris vittata (Chinese ladder fern or Chinese brake fern)* fronds provide an ideal base for diverse arrangements.

✓ *Asparagus densiflorus sprengeri* can be utilized as cascading focal points in larger designs and adds a touch of elegance to delicate flower bouquets.

✓ Decorative branches sourced from plants such as *Eucalyptus, Pittosporum, Murraya* and various other ornamental plants, shrubs and forest trees serve as valuable cut foliage for bouquets and floral arrangements.

Nephrolepis biserrata furcans

Anthurium andreanum

Grevelia robusta leaves

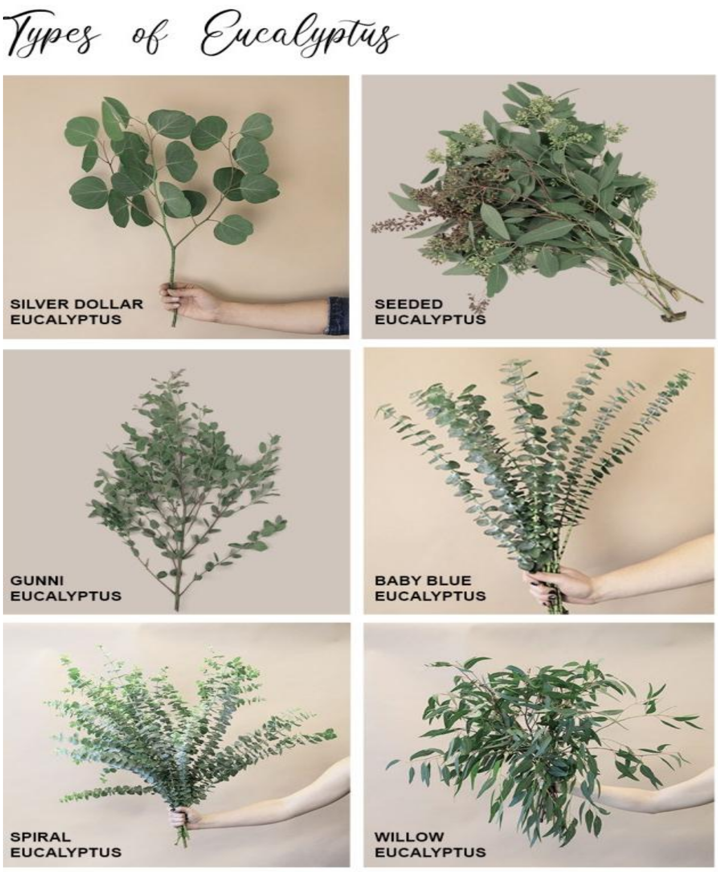
Callistemon

Thuja leaves and seeds

Bouquet using cut foliage

Aralia

Croton leaf




Bird Nest Fern


Lemon button Fern


Acalypha wilkesiana


Hedera helix


Asparagus densiflorus


Monstera deliciosa

Epipremnum pinnatum


Chlorophytum

Importance of cut foliage Industry

1. **Enhances Floral Arrangements:**

- Cut foliage adds texture, volume, and contrast to flower arrangements.
- It serves as a backdrop that highlights the beauty of blooms.
- Used extensively in bouquets, centerpieces, floral displays, and wreaths.

2. **Aesthetic Value:**

- Offers a wide range of shapes, colors (green, silver, variegated), and textures.
- Adds elegance and freshness to floral designs and indoor decorations.
- Foliage types like ferns, palms, and aspidistra create unique design styles.

3. **Economic Significance:**

- Represents a profitable segment of the floriculture industry.
- Generates employment and steady income for growers, especially in tropical and subtropical regions.
- Contributes to both domestic trade and export earnings.

4. **High Demand in International Markets:**

- Widely used by florists, decorators, and event planners globally.
- There is a great demand for many different varieties of cut foliage, particularly in Europe, USA and Japan
- Export potential is growing due to the increasing popularity of floral decor in weddings, festivals, and corporate events.

5. **Year-round Production and Income:**

- Many foliage plants are perennial and can be harvested multiple times a year.
- Provides consistent income compared to seasonal cut flowers.

6. **Low Input, High Return:**

- Requires less maintenance and input cost than many cut flower crops.
- Suitable for small and marginal farmers due to low land and resource requirements.

7. **Environmental Benefits:**

- Cut foliage plants can be grown under partial shade or agroforestry systems.
- Many species improve microclimates and reduce soil erosion.
- Promotes sustainable and eco-friendly farming practices.

8. **Value Addition Opportunities:**

- Can be preserved, dyed, or processed for dried floral crafts and decorations.
- Adds scope for rural women and SHGs in processing and packaging for value-added products.

9. **Diversification in Agriculture:**

- Acts as a tool for crop diversification and reduces dependency on traditional crops.
- Increases farm resilience and risk management through alternative income sources.

10. **Growing Domestic Demand:**

- With rising urbanization, lifestyle changes, and interest in interior decoration, the domestic market for cut foliage is expanding.
- Demand from hotels, malls, offices, and home decorators is steadily increasing.

Classification of Cut Foliage:

In floral design, cut foliage is classified into four main types based on its shape, structure, and function in an arrangement. These are: line, mass, filler, and form foliage. Each type plays a specific role in enhancing the design, structure, and aesthetic appeal of the composition.

	Line Foliage	**Mass Foliage**	**Filler Foliage**	**Form Foliage**
Function	Establishes the framework and structure of an arrangement.	Adds bulk, depth, and volume to arrangements.	Used to fill gaps between flowers and foliage.	Serves as a focal point or accent due to its unique shape or color.
	Directs the viewer's eye movement and sets the height, width, and flow	Used to fill large spaces and support the overall balance	Adds softness and texture, blends elements smoothly	Adds interest, character, and contrast to designs
Characteristics	Long and narrow with a strong linear shape.	Broad, dense leaves or groups of leaves.	Fine-textured with multiple small leaves or sprays.	Unusual or eye-catching in form, pattern, or color.
	Often used in vertical or horizontal designs.	Often have a substantial presence and are placed near focal areas	Creates a delicate and airy effect	Typically used sparingly to avoid overwhelming the design
Examples	Dracaena (e.g., Dracaena marginata), Bamboo leaves, Equisetum (Horsetail), Cordyline and Bear grass	Aspidistra, Monstera, Dieffenbachia, Philodendron and Croton	Leather leaf fern, Ming fern, Pittosporum, Eucalyptus and Ruscus	Calathea, Anthurium leaves, Pandanus, Alocasia and Codiaeum (Croton)

Cultivation Practices

- Soil must be porous and well drained, soil pH 6.0-6.5 with EC of 0.5-1.0 mmhos/sec and bulk density less than 0.75 g/cm3.
- Balanced fertilizers of N, P and K are needed for proper growth.
- Plants should be grown under 50-75% shade.
- Most of these plants perform well if RH is above 50%.
- The least cost net houses could be used for growing foliage plants.

Climate:

- Humid tropical and sub-tropical conditions are best for cut foliage production. Neither high nor freezing temperatures are preferred.
- Optimum temperature range is from 25°C to 28°C Day and 18°C during night.
- Most of the cut foliage crops grow well in 50-75% shade. Both high relative humidity and low temperature is important in reducing moisture loss from foliage.

Light and Temperature

- It is another important factor. Cut foliage crops grow well in bright light, but not under direct sun. It does best in partial shade.
- The foliage will turn yellow in deep shade. Most of the cut foliage crops grow well in 50-75% shade condition.
- Foliage size and shape vary considerably as light intensity changes For example, Philodendron produces larger leaves and longer stem under 40% shade than under 80% shade

- The best general day/night temperature around 32°C and 21°C respectively. Temperature influences rate of photosynthesis and respiration.

Relative humidity:

- Relative humidity plays very important role in cut foliage production. Relative humidity affects transpiration rate and water usage. The lower the relative humidity the more often watering will be required to keep water available and prevent water deficits.
- Commercial growers generally maintain relative humidity level of 50% or more in greenhouse. Cut foliage crops need regular watering, but allow the soil to dry out between watering.

Carbon dioxide: A concentration of carbon dioxide up to 1,500 parts per million will increase plant growth and decrease the time required to propagate foliage plants

Soil:

- Cut foliage plants are very sensitive to soil pH and a slightly acidic soil is preferred.
- A free draining soil is essential. Inadequate aeration will create a favorable soil environment for soil borne fungal diseases.
- The incident of such diseases is lower in light, sandy, free-draining soils. During rainy seasons effective drainage should be allowed.

Potting mixture

- The potting medium used to grow foliage plants can range from 50-100% organic matter and 50% inorganic matter. The major factors to consider in the selection of potting media includes: aeration (capillary and non-capillary pore space), moisture retention (water -holding capacity), nutrient retention (cation exchange capacity), uniformity, availability, C:N ratio, pH, compaction, rate of decomposition, weight and cost.

Methods of propagation

1. Seed: Seed propagation is increasing in popularity because the costs are lower than vegetative methods of propagation, there is no need to maintain stock production areas. Examples: Araucaria, Brassaia, Coffea, Dizygotheca, Podocarpus. Seeds of tropical foliage plants should be sown soon after harvest because the germination percentage decreases rapidly with increased time between harvest and seed sowing.

2. Cuttings: The most popular method. It includes tip, single or double eye leaf bud, and leaf and cane cuttings. Selection of cuttings depends on: plant form (upright, vine), availability of propagative material and healthy, turgid, disease and insect-free stock plants with no nutritional deficiencies. Maximum leaf surface should be left on cuttings for faster and best rooting response as leaves provide carbohydrates and hormones essential for root development

a) Tip cuttings: Through this, plants are produced short period of time. Small cuttings usually root faster and require less space. Tip cuttings should be 10-15 cm long. Cuttings must be placed 3-5 cm deep. *Aglaonema, Diffenbachia, Dracaena* and *Peperomia* are examples.

b) Leaf bud cuttings: The vine-type foliage plants are propagated through leaf bud cuttings. Single eye leaf bud cuttings consists of a short stem section (2 to 4 cm) with an attached leaf. Leaf bud cutting does not produce as many saleable plants as quick as tip cutting, but their initial cost is much less. *Scindapsus aureus* (Golden pothos/Money plant) or *Epipremnum aureum* care propagated by single and double eye leaf bud cuttings.

c) Leaf cuttings: In this method, the largest number of plants is produced from the least propagative stock material. Rex Begonia, Peperomia and species of Sansevieria are propagated from leaf cuttings that do not have chimeras.

d) Stem cuttings: The stem is usually cut with one eye per section but stem sections of 30 to 120 cm are used for *Dracaena massangeana*. Foliage plant cuttings should be pressed in to the potting medium carefully until the stem is barely visible, with the eye facing up and out of the media. Aglaonema, Dieffenbachia and Philodendron are propagated from node cuttings.

e) Division: Division is the only method of propagation of some cultivars of *Sansevieria*. Propagation of *Calathea* (Peacock plant) and *Chlorophytum* ferns and other genera are also obtained by division from parent plants. Healthy disease-free clean stock is especially important when division is used as a method of propagation as nematode diseases and insect related problems are transferred to the new pants.

3. Air layering: Layering is development of roots on the base of the cuttings while it is still attached to the mother plant. Air layering is highly labour intensive and has the problems of desiccation of the material covering the cut portion during dry periods and excess moisture during wet periods. Most air layering foliage plants are *Codiaeum, Dracaenas, Ficus, Monstera, Philodendron*, etc.

4. Runners: Chlorophytum (Spider plant) and *Saxifraga sarmentosa* (Strawberry begonia) are propagated through runners.

5. Spores: Spores are commonly used to propagate a number of fern genera. Spores from mature ferns are placed in a rooting medium. Usually peat and misted or a moisture-tight cover is placed over the seed pan until the plants are large enough to pot. Fern production from spores can take one or two years before saleable plants are available.

Planting

- Foliage plants are generally planted in fields or in pots. Planting can requires investment if done in the pots. Pots can be specially chosen to suit individual plants. Plastic and nonporous pots are available. Watering is needed less frequently in plastic pots than in clay pots. Potting methods fall in two categories: Hand potting, automatic planters.

Irrigation

- Foliage plants are composed of 80% or more water. A water pH of 5.5 to 6.5 is most desirable for foliage plant growth.
- Soluble salt levels should be 500 ppm, but is also acceptable when watered heavily

Stage of harvest

- Stems should be harvested when leaves are mature, dark green and fully expanded.
- Stems should be given slanting cut while harvesting to provide more surface area for water absorption.
- Only 5-7 cm basal portion of the stem should be dipped in water and leaves from dipping portion of the stems should be removed because dipping leaves start rotting and decrease the vase life.

Post-Harvest Factors:

- Foliage plants after harvesting are sprinkled with water prior to the market. The foliage must be fresh until they reach the market. The RH in the cold store is in the range of 85-95% to avoid desiccation.

Plant protection measures

Insects and mites

- Common pest of foliage plants are green flies, mealy bugs, scale insects, red spider mites, thrips, snails and slugs.
- These can be controlled by spraying or dusting or soil drenching with insecticides.
- The factors that affect pest populations are temperature, humidity, potting medium, methods of irrigation.
- Temperature above 26°C in association with low humidity can cause rapid increases in mite populations.
- Cool temperature reduces pest problems in unheated production areas, where as in temperature-controlled greenhouses mites are present year-round.

Diseases

- Foliage plants are less affected by diseases.
- Fungal and bacterial diseases are found when wet foliage is combined with high temperature and humidity.
- These diseases are most prevalent in tropical and subtropical regions with high rainfall.
- Soil-born fungal diseases are more sever when poorer quality growing media, poor aeration and drainage, over watering, viral diseases are not commonly found on foliage plants.
- The most common diseases are grey mold, mildew, root rot and stem canker.
- These fungal diseases can be controlled by spraying or dusting with fungicides.
- Foliar fungal and bacterial disease can be controlled in Greenhouse by keeping the foliage dry.
- Soil drenching for most of the soil-borne diseases is fairly successful

Do's and Dont's of Harvesting Cut Greens/ Foliage

- Optimum stage of harvesting of cut greens is when the growth ceases and the plant attain maturity and has maximum freshness and natural colour
- They are prone to high heat therefore should be kept in a shady, cool place to remove field heat (pre-cooling).
- Should be placed in water immediately after harvesting.
- Do not pile in big heaps.
- Add disinfectant like sodium hypochlorite in the water @ 1000 ppm or change the water regularly.
- Use floral preservative such as 'Shrub chrystal'.
- Remove all dirt or yellowing or diseased foliage.
- Trim, grade, bunch and pack as per individual species and market requirement.
- The bunch of cut foliage should be packed tightly in polythene sleeves to prevent desiccation. Store them at low temperature (2-5 °C) except for foliage of plants like crotons/ dracaenas/ tropical cut greens.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

HOW BLOCKCHAIN IS REVOLUTIONIZING SUPPLY CHAIN TRANSPARENCY IN AGRICULTURE?

Kuppuraj. S and K.J. Sivasangari

B.Sc. (Hons.) Agriculture

Department of Agriculture Entomology, Kumaraguru Institute of Agriculture, Erode

INTRODUCTION

With the world population that projected to reach 9.7 billion by 2050, the demand for food will significantly increase. The Food and Agriculture Organization (FAO) estimates that food production must increase by 70% to meet this demand. The agriculture sector faces numerous challenges, such as labor shortages, market competition, climate change, and sustainability issues. Traditional farming methods are often inefficient and prone to fraud, leading to significant losses. Additionally, small farmers struggle to get fair prices for their produce due to a lack of transparency in the supply chain. So that an emerging trust building process named, Blockchain that can help to manage these risks by providing a transparent and immutable record of transactions, ensuring fair pricing, reducing fraud, and maintaining affordability across the agricultural ecosystem. It assists in Food and Agriculture sector to merge with security and affordability.

What is Blockchain technology?

To a layman, Blockchain is the use in agricultural sector to improve the process and get profitable results with ensured fair prices. According to scientists, Blockchain is a distributed database system with multiple independent nodes. (Li et al., 2020). Those databases are currently handled by ICT (Information and Communication technology) that manages and stores the data. Blockchain is also widely defined as a decentralized, distributed ledger technology that manages and stores/ records the transactions done across multiple computers. It ensures that the recorded transactions cannot be changed and provides security, transparency, and trust.According to Statistics, the Blockchain in the Agriculture and Food Supply Chain Market Size is valued at 403.87 Million in 2023 and is predicted to reach 7,419.9 Million by the year 2031 at a 44.11% CAGR during the forecast period for 2024-2031

Main authorities involved are

(1) National Informatics Centre (NIC)
(2) NITI Aayog (National Institution For Transforming India)
(3) Reserve Bank of India (RBI) and Institute for Development and Research in Banking Technology (IDRBT)
(4) Tamil Nadu e- Governance Agency (TneGA)

Countries efficiently used this Blockchain technology are;

Singapore, El Salvador, Malta, Switzerland, UAE, Korea, Estonia and Canada.

Components of Block Chain Technology

1. **Distributed Ledger Technology**: A decentralized database maintained across multiple nodes that ensures transparency and security.
2. **Smart Contracts and Automation**: These are the digital contracts that stored on a blockchain are automatically executed when predetermined terms and conditions are met.
3. **Security and Integrity**: Utilizes cryptographic algorithms to secure data and transactions, protecting against unauthorized access and fraud.
4. **Asset and Data Management**: Through Tokenization digital tokens created representing assetsor units of value, facilitating exchange and tracking within the supply chain.
5. **Interoperability and User Interaction:** Protocols enabling communication and integration across different blockchain networks and systems. Front-end applications allowing users to interact with the blockchain system.

WORKING MECHANISM OF BLOCKCHAIN TECHNOLOGY

1) **Data Collection:** Collect real-time data and Record farming activities and inputs.

2) **Data Transmission**: Data from IoT devices and farm management systems is transmitted to the blockchain network.
3) **Smart Contract Execution**: Smart contracts are created and deployed on the blockchain and it continuously check for predefined conditions (e.g., delivery confirmation)
4) **Verification Mechanism**: Nodes in the blockchain network verify the data and smart contract conditions.
5) **Validation**: Once verified, the data and contract execution are validated by the network.
6) **Recording of Transactions:**
   Validated transactions are recorded on the distributed ledger, ensuring transparency and immutability.
7) **Tokenization**: Digital tokens representing assets (e.g., crops, payments) are created and recorded.
8) **Supply Chain Tracking and Traceability:** The blockchain tracks the movement of agricultural products through the supply chain, from farm to consumer.
9) **Transparency**: All participants can view the transaction history and status of products.
10) **Payment and SettlementAutomated Payments**: Upon meeting contract conditions, payments are automatically executed and recorded.
    Settlement: Funds are transferred securely between parties.
11) **Data Storage and Access Immutable Records**: All transactions and data are stored immutably on the blockchain.

Access Control: Authorized participants can access and verify records as needed.

APPLICATION IN AGRICULTURE

- **Smart farming**: It incorporates elements such as ICT, the internet of things (IoT), different sensors, machine learning technologies and collection equipment such as unmanned aerial vehicles.
- **Food Supply Chain:**Blockchain technology contributes to the resolution of many of agriculture food supply chain challenges by facilitating the establishment of trust between producers and customers.
- **Agricultural Insurance:** Farmers can choose from a variety of insurance policies that differ in terms of how losses are calculated and payouts are made through Block chain.
- **Transactions of Agricultural Products:** With the use of blockchain technology, the acquisition and selling of agricultural products on ecommerce sites may be substantially accelerated.

ADVANTAGES

1) Transparency (Tracking and tracing of food products)
2) Maintain food safety and security and assess the quality of food products and recall of contaminated products.
3) It stores entire data about the history of food products from origin to reach the consumers.
4) It ensures automatic payment and delivery process i.e smart contracts and maintain the proper stock level without wastage of product
5) Promotes the aware of food products
6) Increases Supply chain efficiency in Agriculture and Food supply.

DISADVANTAGES

- This could be misapplied or misused,at privately held block chains.
- Small-scale farmerswho lack the necessary size and technology of the blockchain,may be left behind,owing to their limited scalability.
- Due to lack of research,many issues are evolved, that issues must be resolved before blockchain technology can be completely incorporated into agriculture.
- While small farms find it simpler to engage in blockchain insurance, larger farms find it easier to gather and integrate diverse sources of real-time farm data. Uploading data to a blockchain is known to be a costly procedure.
- Farmers that cannot afford blockchain face a significant hurdle to adoption and the process of collecting data may be time consuming and costly.

HOW TO OVERCOME CHALLENGES

- **Educating people:** Those who lack the digital literacy required to engage in blockchain technology must be educated.

- Blockchain implementation must be decentralized to accommodate small farmers and even rural dwellers. Otherwise, food security will remain a problem.
- **Eliminating unethical practices**: Blockchain technology can improve security by prohibiting unethical crop production and distribution, which endangers farmers' livelihoods.
- Consumers will be able to make more educated decisions due to blockchain data collection, and they may even be able to help small-scale farmers who are often in need of food and financial security.

CONCLUSION

Blockchain technology holds significant potential to revolutionize the agricultural sector by enhancing transparency, traceability, security and efficiency across multiple supply chains. Its ability to provide immutable records and facilitate decentralized governance through platforms like DAOs can empower and engage farmers, improve market access, and ensure fair pricing. However, the widespread adoption of blockchain faces challenges, including technological barriers, high costs, and the need for greater digital literacy among farmers. While successful in pilot projects, particularly in regions like Tamil Nadu, the full impact of blockchain in agriculture will depend on continued investment, education, and infrastructure development. As the technology advances, it could become a transformative force in ensuring more equitable and efficient agricultural practices across India.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

From Soil to Software: The Tech-Driven Evolution of Farming

Syamprasad Sitra

Chief Manager (Faculty)
SBIRD, Hyderabad

Introduction:

Once based only on seasonal cycles and manual work, agriculture is currently undergoing a significant transition thanks to digital innovation. From preparing the soil to harvesting crops and accessing markets, every stage of the farming cycle is being reshaped by technology. The integration of advanced tools like artificial intelligence (AI), the Internet of Things (IoT), drones, robotics, and cloud computing has given rise to what is known as "either "digital agriculture" or "smart farming." This development aims to make agriculture more resilient, sustainable, and data-driven, not just more efficient. "From Soil to Software" captures this journey of transformation—where age-old practices meet cutting-edge innovation to redefine the future of farming. This article explores how technology is revolutionizing agriculture and shaping the next green revolution.

Precision Agriculture: Data-Driven Farming

Precision agriculture is transforming traditional farming by leveraging data and technology to optimize every aspect of crop production. Farmers can keep an eye on crop health, moisture levels, and soil conditions in real time by utilising tools like GPS, GIS, and IoT sensors. This targeted approach allows for site-specific management, reducing the overuse of water, fertilizers, and pesticides. Drones and satellite imagery further enhance precision by providing aerial views that identify problem areas quickly. Yield monitors on modern machinery collect valuable data during harvesting, enabling farmers to assess productivity across different zones. Artificial intelligence and machine learning algorithms help forecast yields, detect diseases, and support timely decision-making. By reducing input waste and preserving natural resources, precision agriculture also encourages sustainable practices. All things considered, precision farming is a wise and sustainable direction for world agriculture.

Smart Farming with AI and Machine Learning Technologies

Agriculture is undergoing a revolutionary transformation, with Artificial Intelligence (AI) and Machine Learning (ML) playing a pivotal role in shaping its future. AI in agriculture refers to the use of intelligent systems that can analyse vast amounts of data, learn from it, and provide actionable insights. ML, a subset of AI, helps these systems improve over time without being explicitly programmed, making predictions more accurate as more data is collected.

Predictive analytics is one of AI's most significant uses in agriculture. By analysing weather patterns, soil conditions, and historical yield data, AI algorithms can forecast crop diseases, pest outbreaks, and optimal harvesting times. This not only reduces crop losses but also helps in planning and resource management. These tools enable precision interventions, such as applying fertilizers or pesticides only where needed, thus reducing input costs and minimizing environmental harm.

Machine learning is also used in automating machinery and robotics. For example, autonomous tractors, seed planters, and weeding robots are equipped with ML models that help them navigate fields and perform tasks with high accuracy. In livestock farming, AI is used to monitor animal behaviour, health, and nutrition needs, improving productivity and animal welfare.

Despite challenges such as data availability and digital literacy, the integration of AI and ML in agriculture holds immense promise for building a more efficient, resilient, and sustainable food system.

Linked Farm: The Internet of Things (IoT)

The Internet of Things (IoT) is revolutionizing agriculture by transforming traditional farms into intelligent, connected ecosystems. By embedding sensors and devices into farm equipment, soil, water systems, and livestock facilities, IoT enables real-time monitoring, data collection, and automation across the entire agricultural value chain.

Predictive analytics is one of AI's most significant uses in agriculture. Soil moisture sensors detect the exact water needs of different parts of a field, allowing automated irrigation systems to deliver water precisely where and when it is needed. This not only conserves water but also ensures optimal plant health.

IoT also plays a significant role in livestock monitoring. Wearable sensors attached to animals can track their location, behaviour, temperature, and health status. Early detection of illness or abnormal behaviour enables prompt intervention, improving animal welfare and reducing losses. In poultry and dairy farms, IoT devices help manage feeding systems, monitor environmental conditions, and optimize production processes. With real-time alerts and analytics, farmers can address issues proactively rather than reactively.

Moreover, farm machinery such as tractors, harvesters, and planters can be equipped with IoT devices to track their usage, maintenance needs, fuel consumption, and operational efficiency.

The IoT-driven farm not only boosts productivity but also supports sustainability goals by minimizing input use, reducing emissions, and preserving natural resources. It empowers even small and medium farmers with technology that was once limited to large agribusinesses. However, widespread adoption requires reliable internet connectivity, affordable devices, and digital literacy support, especially in rural areas.

Robotics & Automation

Robotics and automation are rapidly transforming agriculture by reducing manual labour and increasing efficiency in farming operations. Robotic harvesters, autonomous tractors, and weeding robots are examples of advanced machines that can consistently and precisely complete repetitive tasks. Farmers may increase agricultural yields, cut labour expenses, and save time with the aid of this technology. Farmers may increase agricultural yields, cut labour expenses, and save time with the aid of this technology. Robotic systems equipped with sensors and AI can identify plant health issues and apply treatments only where necessary, promoting sustainability. In horticulture and greenhouse farming, robots are used for tasks like seeding, pruning, and packaging. Automation also enhances safety by reducing human exposure to chemicals and harsh field conditions. As technology advances, robotics is becoming more accessible even to small and medium-scale farmers, marking a new era of smart agriculture

Big Data & Cloud Platforms

Big data and cloud platforms are playing a vital role in modernizing agriculture by enabling data-driven decision-making. Cloud-based platforms store this data securely and provide real-time access from any location. With advanced analytics, farmers can predict yields, manage resources efficiently, and respond quickly to pests or diseases. These tools also support precision farming by offering zone-specific recommendations for irrigation, fertilization, and planting. Additionally, big data helps in supply chain planning, reducing waste and improving farm-to-market logistics. By leveraging these digital tools, agriculture becomes more efficient, productive, and sustainable.

Controlled Environment Agriculture (CEA)

Controlled Environment Agriculture (CEA) is undergoing a technological renaissance, pushing the boundaries of what indoor farming can achieve. Cutting-edge LED lighting systems now mimic natural sunlight and adjust spectra dynamically to optimize plant growth and energy efficiency. AI-driven climate control systems are becoming standard, automatically tuning temperature, humidity, and CO_2 levels to sustain optimal growing conditions and boost productivity. The rise of robotic and automated systems—from planting and harvesting robots to drone-based monitoring—significantly reduces labour dependency and enhances precision farming. Genetic innovations, like Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) tuned crops adapted for indoor growth, are being piloted to shorten growth cycles and improve resilience Finally, vertical farms are decentralizing through modular, container-based solutions, bringing CEA closer to urban consumers and food deserts

Sustainable Digital Farming

Sustainable digital farming combines modern technology with eco-friendly practices to create a more efficient and environmentally responsible agricultural system. By leveraging tools such as GPS, IoT sensors, AI, and big data, farmers can monitor and manage their resources with precision. These technologies help reduce the overuse of water, fertilizers, and pesticides, thereby minimizing environmental harm. Digital platforms provide real-time insights on soil health, weather, and crop performance, enabling smarter decision-making. Sustainable practices like crop rotation, cover cropping, and reduced tillage are enhanced through data-driven planning. Renewable energy sources such as solar-powered irrigation are increasingly being integrated into farming operations. Overall, sustainable digital farming supports increased productivity while preserving the planet for future generations

Mobile Apps & Farmer-Friendly Platforms

Mobile apps and platforms are empowering farmers with accessible, real-time tools for smarter agriculture. In Maharashtra, the new Vistaar chatbot app delivers AI powered advice on pests, weather, and market trends in Marathi, as part of the state's MahaAgri-AI initiative. Andhra Pradesh's APAIMS 2.0 digital platform offers plot-level pest alerts, personalized advisories, and seamless e-market integration starting from Kharif 2025 Meanwhile, New Zealand's Halter app, paired with smart collars, allows ranchers to virtually fence and manage cattle via mobile—joining their "unicorn" startup. In India, KissanAI's Dhenu 1.0 voice-based LLM supports farmers in English, Hindi, and Hinglish, offering agronomic guidance hands-free. Globally, apps like Plantix continue using AI image-analysis to detect crop diseases—though their evolving business models remind us of the balance between tech and ethics Platforms like Farmonaut combine satellite imagery, AI advisory, and blockchain traceability, offering precision tools even to smallholders.

Challenges and the Way Forward

While technology is rapidly transforming agriculture, the shift from traditional farming methods to data-driven practices brings several challenges. One of the primary barriers is the digital divide, particularly in rural areas where internet connectivity and access to digital tools remain limited. High initial costs of precision equipment, IoT sensors, and AI-based solutions can be prohibitive for small and marginal farmers.

Data privacy and ownership are emerging concerns as vast amounts of farm data are collected and stored on cloud platforms. Without proper regulation, farmers may lose control over their data. Furthermore, interoperability issues between different digital platforms and machinery make integration difficult, limiting the full potential of connected farming ecosystems.

To move forward, there is a pressing need for public-private partnerships to ensure affordable access to technology, infrastructure development, and training programs tailored for farmers. Governments must invest in rural connectivity, subsidize smart tools, and support open-data standards to ensure inclusivity innovations. By addressing these challenges thoughtfully, the promise of “From Soil to Software” can be realized—ushering in a more resilient, productive, and sustainable agricultural future for all.

Conclusion

The journey from soil to software marks a new chapter in the evolution of agriculture one where innovation meets tradition to build a smarter, more sustainable future. By embracing digital tools and data-driven practices, farmers can enhance productivity, conserve resources, and adapt to changing environmental conditions. While challenges like accessibility and digital literacy remain, targeted efforts and inclusive policies can bridge these gaps. The tech-driven evolution of farming is not just a trend—it’s a necessity for feeding a growing world and securing the future of agriculture

References:

Sciencedirect.com
En.wikipedia.org
Businessinsider.com

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Agricultural Marketing Reforms in India: Analyzing Their Impact on Farmer Income and Market Access

[1]Kuldeep Meena, [2]Hitesh Sharma

[1]Research Scholar, Division of Agricultural Economics, RAK College Sehore, Rajmata Vijayaraje Scindia Krishi Vishwavidyalaya, Gwalior

[2]Research Scholar, Division of Agricultural Extension and Education, RAK College Sehore, Rajmata Vijayaraje Scindia Krishi Vishwavidyalaya, Gwalior

Abstract

Agricultural marketing plays a critical role in ensuring farm profitability, efficient distribution of agricultural produce, and the integration of farmers into national and global value chains. In India, agricultural marketing reforms have evolved over the decades to address inefficiencies, exploitation of farmers, and barriers to fair price realization. Reforms such as the Model APMC Act (2003), the introduction of e-NAM (2016), contract farming provisions, the Agricultural Produce and Livestock Marketing (APLM) Act (2017), and the contentious Agricultural Bills (2020) have attempted to reshape the marketing landscape. This paper analyzes the impacts of these reforms on farmer income and market access by exploring their objectives, achievements, challenges, and opportunities. The study also highlights regional disparities in reform adoption, the role of technology in shaping future markets, and policy directions to ensure inclusive and sustainable marketing systems. Findings suggest that while reforms have created new opportunities for farmers through digital platforms, private participation, and Farmer Producer Organizations (FPOs), structural challenges such as inadequate infrastructure, digital illiteracy, and resistance from entrenched stakeholders continue to limit their effectiveness. A forward-looking policy approach focusing on capacity building, market integration, and equitable access is essential for maximizing benefits to farmers.

1. Introduction

Agriculture remains the backbone of India's economy, contributing around 18% of Gross Value Added (GVA) and providing livelihoods to nearly half of the population. However, despite being the world's largest producer of several crops, Indian farmers continue to face challenges in marketing their produce due to inefficiencies in supply chains, inadequate infrastructure, and dominance of intermediaries. For decades, farmers were dependent on Agricultural Produce Market Committees (APMCs), which, while ensuring regulated transactions, also became hubs of inefficiency and rent-seeking.

Agricultural marketing reforms have been at the center of policy debates since independence, but gained momentum in the last two decades. These reforms aimed to liberalize markets, empower farmers with more choices, integrate them with national and global markets, and ultimately improve incomes. In this context, examining the effectiveness of reforms becomes crucial, particularly in light of their implications for doubling farmers' income and ensuring food security. This paper analyzes the trajectory of agricultural marketing reforms in India, their intended objectives, outcomes, and challenges. Special emphasis is placed on understanding how these reforms have affected farmer income and market access, which are critical indicators of agricultural prosperity.

2. Conceptual linkages: How marketing reforms affect farmer incomes and access

Understanding how reforms translate into farmer outcomes requires unpacking several causal channels:

1. **Price Discovery and Competition:** Reforms that increase market competition (through private markets, multiple buyers, and digitized bidding) reduce monopsonistic pressures and should improve price realization for farmers.
2. **Transaction Costs and Efficiency:** Investments in storage, grading, transportation, and market infrastructure reduce losses and costs, raising net returns to farmers.

3. **Market Reach and Diversification:** Allowing trade across mandis, interstate sales, and direct sales to processors/retailers expands the set of potential buyers and can link farmers to more remunerative value chains.
4. **Risk Management and Contracting:** Contract farming and forward contracting can provide price and input security, access to technical assistance, and predictable markets, potentially stabilizing income — though terms and enforcement matter.
5. **Aggregation and Bargaining Power:** Collective marketing through Farmer Producer Organizations (FPOs), cooperatives, and aggregators improves farmers' negotiating position and reduces per-unit costs for logistics and compliance.
6. **Information Asymmetry and Transparency:** Digital platforms and market information systems reduce information asymmetry, enabling farmers to time sales and choose buyers better.
7. **Investment Incentives:** Clearer marketing channels and expected price signals incentivize farmers to invest in higher-value or quality-oriented practices, potentially increasing income.

3. Evolution of marketing reforms in India — an overview

3.1. Pre-reform era and the APMC framework

The APMC framework, enacted state-wise from the 1960s onwards, created regulated market yards, licensed traders, and commission systems aimed at safeguarding farmers. In many regions, however, mandis evolved into oligopolistic hubs: entry barriers, collusion, high fees, and spatial constraints limited farmer choices.

3.2. Early reform impulses: Model APMC Act (2003)

Recognizing the shortcomings, policymakers introduced a Model APMC Act that states could adopt. The Model Act proposed measures such as multiple licensing, direct marketing, private markets, contract farming provisions, and single-point licensing to reduce regulatory chokepoints. Implementation varied markedly across states, as political economy considerations and vested interests shaped uptake.

3.3. Infrastructure and modernization

Reforms included programs to modernize market yards (grading, electronic weighing, warehouses), promote cold chains for perishables, and improve rural road links. These investments sought to reduce post-harvest loss and create the physical backbone for more integrated markets.

3.4. Digital reforms: e-NAM and market information systems

The electronic National Agriculture Market (e-NAM) is a landmark digital initiative to connect APMC mandis on a common trading portal with electronic bidding and price discovery. Complementary platforms emerged to provide price information, weather, and quality standards to farmers.

3.5. Contracts and procurement: enabling direct linkages

Policy measures to legalize and enable contract farming, direct procurement by processors and retail chains, and private markets aimed to bridge farmers to agribusinesses that could absorb large volumes and pay for quality.

3.6. The 2020 Farm Bills and subsequent developments

In 2020, the central government enacted a set of laws to permit greater trade outside mandis, codify contract farming, and deregulate stocking. These laws sparked intense debate and protests. Farmers' concerns about market access, MSP protection, and corporate power led to calls for more safeguards; political backlash culminated in the laws being repealed in 2021. The episode underscored the sensitivity of agricultural marketing reform to trust, sequencing, and safety nets.

4. Empirical evidence and observed impacts on farmer incomes and market access

Assessing the impact of reforms requires looking at both broad trends and localized evidence. While cross-country lessons and state-level experiments show promise, outcomes are heterogeneous.

4.1. Price realization and reduced marketing margins

Where reforms and market modernization have been implemented effectively (market modernization, private procurement, functioning e-auctions), farmers often realize better prices through transparent bidding and access to more buyers. Reduced intermediation and lower commission rates have improved net returns in some commodity markets and regions.

4.2. Diversification into higher-value crops

Improved market access encourages crop diversification into horticulture, vegetables, and high-value commodities where price premiums are available. However, diversification requires complementary investments — cold chains, grading, and season-specific logistics — without which increased market access remains of limited value.

4.3. Reduced post-harvest losses and seasonal distress selling

Upgraded storage and cold chain facilities, including private warehouses and farmer-operated storage, reduce forced distress sales in gluts, allowing better timing of market entry and improved price capture.

4.4. Impact of contract farming and direct procurement

Contracting has provided some farmers with assured markets, technical support, and pre-payments, improving incomes and reducing market risk. Yet, benefits are uneven — smallholders without scale or contractual literacy may be vulnerable to exploitative terms if enforcement is weak.

4.5. Effects mediated by aggregation (FPOs/cooperatives)

FPOs and well-run cooperatives that aggregate produce and negotiate contracts have achieved better price realization for members. Aggregation reduces unit transaction costs, enables quality compliance, and improves access to formal buyers.

4.6. Digital marketplace impacts (e-NAM and similar platforms)

Digital platforms increase the pool of potential buyers and facilitate price discovery. However, uptake has been constrained by connectivity gaps, limited physical integration (i.e., linkage of e-transactions to logistics), and low digital literacy among farmers. Where linkages exist (e-procurement integrated with warehousing, reliable payment systems), digital markets have enhanced farmer reach and choice.

5. Regional and commodity variations in impacts

Marketing reforms do not benefit all regions or commodities equally. Key variations include:

5.1. State-level policy adoption and political economy

States that proactively amended APMC laws, invested in market infrastructure, and promoted FPOs recorded more evident gains in farmer access and incomes. Where political resistance to reform remained high, barriers persisted.

5.2. Commodity characteristics

- **Grains (wheat, paddy):** Grain markets depend heavily on public procurement mechanisms (MSP), which provide price support but create dependence on procurement infrastructure. Reforms that expand private procurement can provide alternatives but must operate alongside MSP to protect farmers.
- **Horticulture and perishables:** These sectors most benefit from improved market access and cold chains, as margin improvement is significant. However, perishability demands robust logistics.
- **Cash crops and exportables:** Better market linkages and contract farming can connect producers to processors/ exporters, supporting income growth for quality producers.

5.3. Farm size and smallholder dynamics

Smallholders, who are a majority in India, often face constraints to exploiting new market opportunities due to lower bargaining power, inability to meet quality or volume thresholds, and limited access to finance and technology. Reforms that rely on individual access without strong aggregation mechanisms tend to bypass smallholders.

6. Institutional and operational bottlenecks limiting reform impacts

Despite potential, several bottlenecks limit reforms' effectiveness in raising incomes and expanding access:

6.1. Infrastructure deficits: Cold chains, warehouses, grading and sorting units, rural roads, and market yards are uneven across regions. Without physical infrastructure, market access remains theoretical.

6.2. Fragmented regulations and interstate barriers: Agricultural marketing being a state subject leads to regulatory fragmentation. Differing rules, taxes, and licensing regimes constrain interstate trade and complicate larger market integration.

6.3. Digital and skills gaps: Connectivity, reliable internet, and farmer familiarity with digital tools are uneven. Even where e-platforms exist, low digital literacy and lack of user-friendly interfaces restrict usage.

6.4. Power asymmetries and market concentration: Large buyers and processors may exercise market power; absent collective farmer bargaining, farmers may still receive unfavorable terms. Market concentration can also reduce the competitive gains from liberalization.

6.5. Trust, enforcement, and contract credibility: Contract farming and off-mandi transactions depend on enforceable contracts and quick grievance redressal. Weak institutions and costly legal recourse deter small farmers from entering contracts.

6.6. Financial constraints and risk exposure: Farmers need working capital, storage finance, and risk mitigation tools (insurance, forward contracts). Without affordable finance, farmers cannot hold produce for better prices or invest in quality enhancement.

7. The role of aggregation and institutional innovations (FPOs, cooperatives)

Aggregation is a pivotal mechanism for enabling smallholders to benefit from marketing reforms.

7.1. Farmer Producer Organizations (FPOs): FPOs can purchase inputs collectively, aggregate produce, negotiate contracts, and operate processing or storage facilities. Well-managed FPOs reduce transaction costs, assure quality, and enhance bargaining power. Capacity building, governance, and access to affordable finance are critical to their success.

7.2. Cooperatives and producer companies: Historically successful cooperatives (e.g., dairy) illustrate how aggregation can deliver stable incomes. Producer companies present an enterprise model that can manage market linkages while remaining producer-centric.

7.3. Contractual partnerships with private sector: Public–private or PPP models where FPOs partner with processors or retailers can enable guaranteed offtake, technical assistance, and market access, provided contracts are transparent and enforceable.

8. Digital platforms, market information, and traceability

Digital systems, when integrated with physical logistics and payment systems, multiply the benefits of reforms.

8.1. Market information systems and price transparency: Timely price information enables farmers to choose sale timing and buyers. However, information alone is insufficient without choice of buyers and logistical capacity.

8.2. Electronic trading and e-auction systems: Electronic bids reduce collusion possibilities and open markets to non-local buyers. For perishable produce, real-time matching and logistics integration are essential.

8.3. Traceability and quality compliance: Digital traceability systems support entry into high-value supply chains (retail, export) by assuring quality and compliance, enabling price premiums for certified produce.

9. Welfare and distributional considerations

Reforms can have differential distributional impacts that require attention:

9.1. Gains for better-connected farmers: Farmers with larger holdings, proximity to infrastructure, higher literacy, or established aggregator relationships often capture larger gains.

9.2. Risk of exclusion for marginal farmers: Without aggregation, subsidies, or targeted capacity building, marginal farmers risk exclusion from formal supply chains and may remain dependent on local intermediaries.

9.3. Gender dimensions: Women farmers often have less access to land titles, formal markets, mobile phones, and finance. Reforms must incorporate gender-sensitive interventions to ensure equitable access.

10. Policy lessons and recommendations

To ensure reforms translate into broad-based gains for farmer income and market access, the following measures are vital:

10.1. Sequencing and safeguards: Reform sequencing must ensure that liberalization is accompanied by strengthened infrastructure, accessible finance, and legal safeguards (e.g., on contract enforcement and dispute resolution). Maintaining MSP and procurement systems for staple crops while expanding private pathways can sustain farmer confidence.

10.2. Invest in infrastructure and logistics: Public and private investments in cold chains, warehousing, grading, and rural roads are prerequisites to realize the price and access benefits of reforms.

10.3. Strengthen aggregation models: Targeted support for FPOs and cooperatives — training, governance assistance, access to concessions/credit, and market linkages — enables smallholders to aggregate and capture value.

10.4. Digital inclusion and integrated systems: Scale up rural connectivity, create user-friendly digital interfaces (voice/vernacular), and integrate e-market platforms with logistics and payment systems.

10.5. Regulatory harmonization and interstate trade facilitation: Harmonize market rules, licensing, and tax regimes to reduce friction in interstate trade and create seamless national markets with clear grievance mechanisms.

10.6. Contract law clarity and enforcement mechanisms: Establish accessible, cost-effective dispute resolution mechanisms for agricultural contracts and protect smallholders from predatory clauses.

10.7. Strengthen market intelligence and extension: Market extension services that help farmers understand demand, quality standards, and grading improve their ability to participate in value chains.

10.8. Build trust and participatory policy design: Engage farmer organizations in policy design, pilot reforms with stakeholder inputs, and create transparent communication to build trust.

11. Future outlook

Agricultural marketing in India stands at an inflection point. Technology, changing consumption patterns (greater demand for processed and safe foods), and globalization create opportunities for higher farmer incomes if reforms are implemented inclusively. Growing urbanization and retail expansion will continue to create demand for quality produce; farmers who can meet quality, volume, and traceability requirements will capture premium prices. The combination of aggregation (FPOs), smart digital platforms, and strengthened infrastructure can transform market access for smallholders. However, it will require sustained, well-sequenced policy actions and investments to avoid deepening inequities.

12. Conclusion

Marketing reforms have the theoretical potential to substantially improve farmer incomes and market access by enhancing competition, transparency, and market reach. Empirical experiences show that where reforms are complemented by infrastructure, aggregation, digital inclusion, and regulatory clarity, farmers including smallholders can capture higher returns. Conversely, reforms implemented without supporting investments and safeguards risk benefiting better-equipped farmers while excluding the most vulnerable.

A pragmatic approach to marketing reform in India should combine liberalized market access with protective measures: invest heavily in market infrastructure, foster aggregation and capacity building, scale digital systems in a user-friendly manner, harmonize regulatory frameworks, and ensure accessible enforcement and grievance redressal. With such a balanced and inclusive strategy, agricultural marketing reforms can become a powerful lever for increasing farmer incomes, reducing rural poverty, and building resilient agricultural value chains.

References:

Kumar, P., Mishra, S., Khanna, V., Roy, P., Nayak, A., Baldodiya, V. K., ... & Pundir, R. S. (2023). Impact of Marketing Reforms on Farm-Market Linkages. In *Sustainable Food Value Chain Development: Perspectives from Developing and Emerging Economies* (pp. 239-257). Singapore: Springer Nature Singapore.

Lundberg, M. (2005). Agricultural market reforms. *Analyzing the distributional impact of reforms*, *1*, 145-212.

Ghosh, N. (2013). India's agricultural marketing. *India studies in business and economics ReDIF-Book*, 83-106.

Roy, D. (2022). Agriculture Marketing in India: Perspectives on Reforms and Doubling Farmers' Income. *Journal of Marketing Development & Competitiveness*, *16*(3).

Goyal, A. (2010). Information, direct access to farmers, and rural market performance in central India. *American Economic Journal: Applied Economics*, *2*(3), 22-45.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Digital Extension Services in Agriculture: Revolutionizing Knowledge Transfer and Advisory Support in Rural India

Gottimukkula Sree Pooja[1], Bhanita Baruah[2], Saithala Mounika[3], Apurba Baruah[4], Siddhartha Sankar Saikia[5]

[1]PhD Scholar, Department of Agricultural Extension Education, Professor Jayashankar Telangana Agricultural University, Hyderabad-500030, India
[2]PhD Scholar, School of Social Sciences, CPGS-CAU, Umiam, Meghalaya, India
[3]PhD Scholar, Department of Agronomy, Professor Jayashankar Telangana Agricultural University, Hyderabad-500030, India
[4]Young Professional -II, ATARI, Guwahati, Assam, India
[5]Agricultural Development Officer, ADO, Dhemaji, Assam, India

Abstract

Agricultural extension has always been central to bridging the gap between research institutions and farming communities. However, conventional extension approaches in India have faced persistent limitations such as limited outreach, resource constraints, lack of personalization, and inadequate responsiveness to farmers' needs. In recent decades, the rapid penetration of mobile phones, internet connectivity, and digital innovations has transformed the landscape of agricultural knowledge transfer. Digital extension services delivered through mobile applications, call centers, interactive platforms, social media, and advanced technologies like artificial intelligence (AI), big data, and the Internet of Things (IoT) are revolutionizing the delivery of agricultural information and advisory support. These services provide real-time weather forecasts, market intelligence, pest and disease advisories, crop management tips, and price discovery mechanisms, enabling farmers to make informed decisions, reduce risks, and enhance productivity.

This paper explores the evolution, ecosystem, tools, and impacts of digital extension services in rural India. It analyzes their role in improving inclusivity, strengthening climate-smart agriculture, and empowering smallholder farmers. The paper also highlights challenges such as the digital divide, low digital literacy, infrastructure gaps, financial sustainability, and issues related to trust and data privacy. It further outlines strategies and policy recommendations for strengthening digital extension through public-private partnerships, integration with Farmer Producer Organizations (FPOs), and capacity building. Finally, it emphasizes future prospects for digital agriculture, where AI, IoT, and blockchain technologies will redefine extension systems and make them more interactive, inclusive, and farmer-centric.

1. Introduction

Agriculture in India continues to be the backbone of the rural economy, employing nearly half of the workforce and sustaining millions of livelihoods. Despite its central role, the sector has struggled with productivity challenges, low adoption of modern practices, and vulnerability to climate change. One of the critical reasons for these constraints lies in the inefficiency of knowledge transfer systems. Agricultural extension services, traditionally delivered through state extension officers, Krishi Vigyan Kendras (KVKs), and farmer meetings, have played a vital role in disseminating new technologies and practices. However, the conventional system has been limited in outreach, unable to reach millions of smallholder farmers spread across diverse agro-ecological zones.

In the past two decades, India has witnessed a communication revolution. With mobile penetration exceeding 1.2 billion connections and internet access expanding even in remote rural areas, the possibilities for digital transformation in agriculture have multiplied. This has opened up new pathways for delivering advisory support, market information, weather forecasts, and knowledge sharing at scale. Digital extension services now bridge the gap between research institutions, extension agencies, and farmers, offering timely, cost-effective, and tailored solutions.

The relevance of digital extension becomes even more significant in the context of climate change, market volatility, and resource constraints. Farmers today need quick, reliable, and location-specific advisory services. A farmer growing rice in eastern India requires different guidance compared to one cultivating millets in arid zones of Rajasthan. Traditional models have struggled to provide this level of personalization. Digital technologies, however, through mobile-based platforms, big data analytics, and AI-driven advisories, can deliver tailored recommendations based on soil type, crop variety, weather conditions, and market demand. This paper examines how digital extension services are revolutionizing agricultural knowledge transfer and advisory support in rural India. It delves into their evolution, the current ecosystem of players, the tools and technologies used, their impacts, the challenges they face, and the strategies needed to strengthen them.

2. Concept and Evolution of Digital Extension Services

2.1. Definition and Scope

Digital extension services refer to the use of information and communication technologies (ICTs) and digital platforms to deliver agricultural advisory, knowledge, and services directly to farmers. Unlike traditional extension, which depends on in-person interactions, digital extension leverages mobile phones, computers, internet connectivity, and multimedia tools to reach wider audiences at scale.

The scope of digital extension includes:

- Providing timely advisory on crop cultivation, pest management, soil health, and irrigation.
- Delivering weather forecasts and early warning systems.
- Facilitating market access, price discovery, and e-trading platforms.
- Enabling two-way communication between farmers and experts.
- Building networks and knowledge-sharing communities among farmers.

2.2. Historical Transition from Traditional to Digital Models

In the early decades after independence, agricultural extension in India was dominated by face-to-face methods such as demonstration plots, farm visits, and farmer training camps. While effective in small communities, these approaches became increasingly inadequate for a vast and diverse farming population.

The first wave of ICT-based extension emerged in the late 1990s and early 2000s with the establishment of internet kiosks, call centers, and rural knowledge centers. Initiatives like e-Choupal by ITC, Warana Wired Village Project, and Gyandoot demonstrated how digital platforms could connect farmers to information and markets. These models, however, were localized and often donor-driven.

The second wave, from 2010 onwards, coincided with the rise of mobile connectivity in rural India. SMS-based advisories, interactive voice response (IVR) systems, and mobile applications became prominent tools. The government launched programs such as mKisan and Kisan Call Centers, while private agri-tech startups began offering services ranging from crop advisory to input supply and market linkage.

Today, digital extension is entering a third wave, characterized by advanced technologies such as AI, big data analytics, remote sensing, and IoT. These innovations enable hyper-local and predictive advisories, moving extension from reactive information-sharing to proactive, data-driven decision support.

2.3. Global Perspectives on Digital Extension

Globally, digital extension has been recognized as a transformative force in agriculture. In Africa, mobile-based services like M-Pesa and iCow provide financial inclusion and advisory support. In developed countries, digital farming platforms integrate farm machinery, sensors, and satellite data for precision agriculture. India's digital extension movement reflects a hybrid approach leveraging low-cost mobile technologies while gradually incorporating advanced digital tools.

3. Digital Extension Ecosystem in India

3.1. Government Initiatives

The Government of India has been at the forefront of promoting digital agriculture. Platforms such as **mKisan Portal**, **Kisan Call Centers**, and **e-NAM (National Agriculture Market)** have transformed farmer access to advisory services and market information. The development of **AgriStack** as a digital ecosystem for agriculture promises to consolidate farmer databases, advisory tools, and market services under a single umbrella.

3.2. Role of Private Sector and Startups

Private companies and agri-tech startups have developed innovative digital platforms that provide personalized advisories. Mobile apps offer solutions ranging from soil testing and weather forecasts to crop insurance and credit linkages. Companies like AgroStar, DeHaat, and Gramophone have connected millions of farmers to expert advice, inputs, and markets.

3.3. NGOs and Farmer Organizations

Non-governmental organizations and Farmer Producer Organizations (FPOs) play a crucial role in digital extension. They act as intermediaries, ensuring that digital tools reach grassroots communities. By training farmers and integrating them into digital ecosystems, these organizations bridge the digital literacy gap.

4. Key Tools and Platforms in Digital Extension

4.1. Mobile Applications and SMS Services

Mobile phones are the backbone of digital extension. Apps provide crop advisories, weather updates, pest management solutions, and price information. SMS-based services remain vital for farmers with basic phones.

4.2. Interactive Voice Response (IVR) and Call Centers

IVR systems allow farmers to dial in and receive recorded messages in local languages. Kisan Call Centers connect farmers to agricultural experts, enabling two-way communication.

4.3. Social media and WhatsApp-based Advisory

Social media platforms and messaging services like WhatsApp have emerged as informal yet powerful tools for farmer advisories. They facilitate peer-to-peer learning, group discussions, and dissemination of government schemes.

4.4. Artificial Intelligence, Big Data, and Decision Support Systems

AI-driven platforms provide predictive advisories on weather, pest infestations, and crop health. Big data analytics enables personalized recommendations by integrating soil data, climatic conditions, and market trends.

4.5. Remote Sensing, GIS, and Precision Agriculture Tools

Satellite imagery and GIS tools support precision agriculture by helping farmers manage irrigation, fertilization, and pest control more effectively. These technologies make farming more resource-efficient and climate-resilient.

5. Impact of Digital Extension Services

5.1. Enhancing Access to Information and Knowledge: Digital platforms provide farmers with timely access to critical information, reducing dependency on middlemen and unreliable sources.

5.2. Improving Technology Adoption and Productivity: Farmers adopt improved seeds, fertilizers, and mechanization more readily when they receive digital advisory support, leading to higher yields and income.

5.3. Facilitating Market Linkages and Price Discovery: Platforms like e-NAM connect farmers directly to buyers, reducing exploitation and improving price realization.

5.4. Strengthening Climate-Smart and Sustainable Agriculture: Digital advisories provide early warnings of pest outbreaks and weather events, enabling farmers to take preventive measures and reduce losses.

5.5. Inclusion of Women and Youth in Agriculture: Women and rural youth, often excluded from traditional extension, benefit greatly from mobile-based platforms, which are accessible and flexible.

6. Challenges in Scaling Digital Extension Services

6.1. Digital Divide and Connectivity Issues: Despite progress, rural areas still suffer from poor internet connectivity and limited smartphone penetration.

6.2. Literacy and Capacity Barriers: Low levels of digital literacy among farmers hinder effective use of digital tools.

6.3. Data Privacy, Ownership, and Trust Issues: Concerns about who controls farmer data and how it is used remain a barrier to adoption.

6.4. Financial Sustainability and Institutional Support: Many digital platforms rely on donor or government funding, raising questions about long-term sustainability.

7. Strategies for Strengthening Digital Extension

7.1. Bridging the Digital Divide: Investing in rural internet connectivity and affordable devices is crucial.

7.2. Public-Private Partnerships: Collaboration between government, private companies, and NGOs ensures wider outreach and innovation.

7.3. Capacity Building: Training programs for farmers and extension agents must focus on digital literacy.

7.4. Integration with FPOs: Farmer Producer Organizations can act as local hubs for digital advisory dissemination.

7.5. Policy and Regulatory Frameworks: Robust policies are required to safeguard farmer data and promote innovation in digital agriculture.

8. Future Prospects and Research Needs

8.1. Role of AI, IoT, and Blockchain: Emerging technologies promise to revolutionize digital extension by making it more precise, predictive, and transparent.

8.2. Climate-Resilient Agriculture: Digital advisories will play a vital role in helping farmers adapt to climate change by providing early warning systems.

8.3. Integration into National Agricultural Policies: Digital extension must be mainstreamed into agricultural policies and programs to ensure sustainability.

8.4. Research Gaps: Further research is needed to assess the long-term impact of digital extension on farmer income, social equity, and rural transformation.

9. Conclusion

Digital extension services represent a transformative approach to agricultural knowledge transfer in India. By leveraging ICTs, mobile platforms, AI, and precision tools, these services empower farmers with timely information, improve productivity, and strengthen resilience. However, challenges such as the digital divide, literacy gaps, and sustainability must be addressed to ensure inclusivity. With strong policy support, capacity building, and partnerships, digital extension can serve as a powerful instrument of rural empowerment, contributing to food security and sustainable agricultural growth.

References:

Khatri, A., Lallawmkimi, M. C., Rana, P., Panigrahi, C. K., Minj, A., Koushal, S., & Ali, M. U. (2024). Integration of ICT in agricultural extension services: A review. *Journal of Experimental Agriculture International*, *46*(12), 394-410.

Prajapati, C. S., Priya, N. K., Bishnoi, S., Vishwakarma, S. K., Buvaneswari, K., Shastri, S., ... & Jadhav, A. (2025). The role of participatory approaches in modern agricultural extension: bridging knowledge gaps for sustainable farming practices. *Journal of Experimental Agriculture International*, *47*(2), 204-222.

Priya, N. K., Patil, S. S., Vishwakarma, S. K., Saikanth, D. R. K., Mishra, I., Tripathi, S., ... & Shastri, S. (2025). Digital Innovations in Extension Education: A Review of Emerging Technologies and their Impact on Agricultural Knowledge Dissemination. *Journal of Experimental Agriculture International*, *47*(5), 408-423.

Singh, N. K., Sunitha, N. H., Tripathi, G., Saikanth, D. R. K., Sharma, A., Jose, A. E., & Mary, M. V. (2023). Impact of digital technologies in agricultural extension. *Asian Journal of Agricultural Extension, Economics & Sociology*, *41*(9), 963-970.

Jarial, S. (2023). Internet of Things application in Indian agriculture, challenges and effect on the extension advisory services–a review. *Journal of Agribusiness in Developing and Emerging Ec onomies*, *13*(4), 505-519.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Farm Mechanization in India: Economic Viability and Implications for Smallholder Farmers

Priyesh Ranjan[1], Anil Singh Rawat[2], Gopesh Kumari[3]

[1]Research Scholar, Department of Agricultural Economics, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh
[2]Research Scholar, Department of Agricultural Economics, Chimanbhai Patel College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar
[3]Research Scholar, Department of Agricultural Economics, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan

Abstract

Farm mechanization has emerged as a key driver of agricultural modernization, enabling timely operations, improved efficiency, and higher productivity. In India, where nearly 86 percent of farmers are small and marginal, the adoption of farm machinery has significant implications for economic viability, employment, and livelihood security. This paper critically examines the status, economic viability, and challenges of farm mechanization in India, with a special focus on its impact on smallholder farmers. The analysis highlights the cost–benefit dimensions, productivity gains, labor substitution, and environmental consequences of mechanization. It also explores the role of Custom Hiring Centers (CHCs), government policies, and innovations in machinery tailored to small and fragmented holdings. While mechanization offers clear benefits in terms of efficiency and income, the barriers of high capital cost, limited credit access, and fragmented landholding patterns restrict its equitable adoption. The paper concludes by recommending inclusive strategies such as scaling up cooperative models, promoting rental services, investing in small-scale and eco-friendly machinery, and integrating mechanization with digital platforms to ensure that smallholder farmers benefit from mechanization in a sustainable manner.

1. Introduction

Agriculture continues to play a pivotal role in India's economy, employing nearly half of the workforce and contributing about 18 percent to the national GDP. Despite this, Indian agriculture is characterized by small and fragmented landholdings, labor-intensive practices, and relatively low productivity compared to global standards. Farm mechanization has emerged as a crucial instrument to address these challenges by reducing drudgery, enhancing efficiency, and increasing profitability.

Globally, mechanization has been instrumental in transforming agricultural systems, yet in India, the process has been uneven. While regions like Punjab, Haryana, and western Uttar Pradesh exhibit high levels of mechanization due to large landholdings and favorable agro-ecological conditions, eastern, central, and northeastern states lag significantly. This disparity underscores the importance of contextual and inclusive mechanization strategies.

The economic viability of farm mechanization depends on the balance between cost and benefits. For large farmers, machinery investment is often profitable due to economies of scale. However, small and marginal farmers face challenges because high fixed costs of machinery cannot be justified on small landholdings. Custom Hiring Centers (CHCs) and rental services have been developed as innovative models to bridge this gap, but their reach and efficiency remain limited. This paper aims to provide a comprehensive assessment of the economic viability of farm mechanization in India and its implications for smallholder farmers. It explores historical evolution, economic impacts, policy frameworks, challenges, and potential strategies for inclusive mechanization.

2. Overview of Farm Mechanization in India

2.1. Historical Evolution

The introduction of farm machinery in India dates back to the Green Revolution of the 1960s, which accelerated the use of tractors, pump sets, and threshers. Mechanization became closely tied to intensive cropping systems such as rice–wheat, where timely sowing and harvesting were essential. Over time, innovations expanded to include combine harvesters, power tillers, and machinery for precision farming.

2.2. Current Status

India's average level of mechanization stands at about 45–50 percent, compared to 90 percent in developed countries like the USA and Japan. Tractors dominate the mechanization landscape, accounting for nearly 50 percent of total farm power availability. However, significant gaps remain in mechanizing operations such as sowing, weeding, inter-culture, and post-harvest processing.

2.3. Regional Disparities

Mechanization is highly uneven across regions. Northern states such as Punjab, Haryana, and Uttar Pradesh have achieved higher mechanization levels due to larger holdings and better infrastructure. In contrast, eastern states like Bihar, West Bengal, and Assam, along with much of the northeast, remain under-mechanized due to fragmented holdings, poor infrastructure, and high labor availability.

2.4. Emerging Trends

Recent years have seen innovations in ICT-enabled mechanization, including drone-based applications, precision seeders, and mobile-based platforms for machinery rentals. Increasing emphasis is also being placed on machinery suited for small holdings, such as mini-tractors, lightweight harvesters, and solar-powered equipment.

3. Economic Viability of Farm Mechanization

3.1. Cost–Benefit Analysis

The economic benefits of mechanization are evident in terms of higher productivity, reduced labor costs, and timeliness of operations. Studies show that mechanized farming can increase crop yields by 15–20 percent and reduce labor requirements by 20–30 percent. For crops like wheat and paddy, mechanized sowing and harvesting significantly cut costs per unit output.

However, the high upfront capital cost of machinery such as tractors and harvesters reduces its viability for smallholders. A tractor, for instance, requires at least 15–20 hectares of regular operation to be economically justified, whereas the average landholding in India is just 1.08 hectares.

3.2. Mechanization and Productivity Gains

Mechanization improves input-use efficiency by ensuring better seed placement, uniform irrigation, and precise fertilizer application. It enables multiple cropping, reduces turnaround time between harvest and sowing, and enhances cropping intensity. For example, zero-till seed drills in wheat cultivation after paddy harvest save costs on land preparation while improving yields.

3.3. Labor Substitution Effects

Mechanization substitutes human and animal labor, thereby reducing drudgery and dependence on seasonal labor availability. In states with high rural–urban migration, mechanization fills the labor gap. However, it may also reduce employment opportunities for agricultural laborers, leading to socio-economic challenges.

3.4. Returns on Investment

Large farmers enjoy positive returns on investment in machinery due to higher operational area. In contrast, smallholders often fail to recover costs, unless they lease machinery through CHCs. Group ownership and rental services thus become critical in ensuring the viability of mechanization for small farmers.

4. Implications for Smallholder Farmers

4.1. Challenges of Ownership

Smallholders face severe constraints in owning machinery due to high costs and low landholding sizes. Even with subsidies, ownership remains uneconomical for most.

4.2. Custom Hiring Centers (CHCs)

CHCs and rental models offer an affordable alternative by allowing farmers to access machinery on a pay-per-use basis. Government schemes such as Sub-Mission on Agricultural Mechanization (SMAM) have promoted CHCs, though their penetration remains limited and uneven.

4.3. Access to Credit and Subsidies

Institutional credit remains skewed in favor of larger farmers, and smallholders often lack collateral for loans. While subsidies are available for machinery purchases, small farmers frequently face barriers in accessing them due to bureaucratic hurdles and lack of awareness.

4.4. Gender and Inclusiveness

Mechanization has mixed impacts on gender equity. While reducing women's drudgery in manual tasks, it sometimes displaces women from agricultural wage labor. Designing gender-friendly tools and involving women in mechanization services can improve inclusiveness.

5. Socio-Economic and Environmental Dimensions

5.1. Employment and Rural Labor Dynamics

Mechanization alters rural labor markets by reducing demand for manual labor in operations like plowing and harvesting. However, it also creates new employment opportunities in machinery repair, maintenance, and rental services.

5.2. Crop Diversification and Cropping Intensity

Mechanization allows for timely sowing and harvesting, enabling farmers to adopt crop diversification and increase cropping intensity. This improves overall income and food security.

5.3. Environmental Considerations

While mechanization improves efficiency, it also raises concerns about energy consumption and greenhouse gas emissions. Heavy machinery may contribute to soil compaction and degradation. Promoting eco-friendly, lightweight, and renewable-energy-based machinery is critical to mitigate such risks.

6. Policy Framework and Institutional Support

6.1. Government Mechanization Schemes

India has several policies supporting mechanization, including the Sub-Mission on Agricultural Mechanization (SMAM), Rashtriya Krishi Vikas Yojana (RKVY), and the establishment of CHCs. These schemes focus on providing subsidies, promoting rental services, and supporting innovation in small-scale machinery.

6.2. Role of Cooperatives and FPOs

Cooperatives and Farmer Producer Organizations (FPOs) can act as collective platforms for machinery access, reducing costs for individual smallholders. Group-based ownership models have shown promise in states like Maharashtra and Tamil Nadu.

6.3. ICT and Digital Platforms

Digital tools and mobile apps are emerging as effective mechanisms for connecting farmers with service providers. Platforms like "Trringo" and "EM3 Agri Services" provide on-demand rental services, similar to the Ola/Uber model, for farm machinery.

7. Challenges and Barriers to Mechanization

1. **Fragmented Landholdings** – Small and scattered plots reduce the efficiency of machinery use.
2. **High Capital Costs** – Tractors, harvesters, and other machines are financially out of reach for most farmers.
3. **Credit Constraints** – Limited access to institutional finance hampers ownership.
4. **Lack of Awareness and Training** – Many farmers are unaware of available machinery or lack technical know-how.
5. **Regional Disparities** – Eastern and northeastern regions lag behind due to socio-economic and infrastructural barriers.

8. Future Prospects and Strategies

8.1. Climate-Smart Mechanization

Adapting mechanization to climate-smart practices such as precision seeding, conservation tillage, and water-efficient irrigation will be vital.

8.2. Innovations in Small Machinery

Developing low-cost, lightweight machinery tailored for small farms can enhance accessibility. Examples include mini-tractors, solar-powered pumps, and multi-purpose hand tools.

8.3. Public–Private Partnerships

Private sector investment in rental services, machinery development, and digital platforms will complement government initiatives.

8.4. Integrating Mechanization with Digital Agriculture

Linking machinery with precision farming, IoT, and AI-based advisory systems can improve resource-use efficiency and profitability.

9. Conclusion and Recommendations

Farm mechanization is a cornerstone of agricultural modernization in India, offering clear benefits in terms of productivity, efficiency, and income enhancement. However, its economic viability is uneven across farm sizes, with smallholders facing significant barriers to adoption. While rental models, subsidies, and cooperative platforms have improved access, much remains to be done to ensure inclusive mechanization.

Key Recommendations:

- Strengthen **Custom Hiring Centers** and promote digital rental services.
- Develop **affordable, small-scale, and eco-friendly machinery** tailored to smallholders.
- Enhance **institutional credit and subsidies** targeted at small and marginal farmers.
- Encourage **cooperative and FPO-based ownership models** to reduce individual costs.
- Integrate mechanization with **climate-smart and digital agriculture** practices for long-term sustainability.

A balanced approach that combines economic viability with inclusiveness will ensure that farm mechanization serves as a true enabler of agricultural transformation, improving livelihoods and food security for millions of smallholder farmers in India.

References:

Sekhar, C. S. C., & Bhatt, Y. (2014). Effect of farm mechanization on agricultural growth and comparative economics of labour and machinery in India. *Institute of Economic Growth, New Delhi, India*.

Pingali, P. (2007). Agricultural mechanization: adoption patterns and economic impact. *Handbook of agricultural economics*, *3*, 2779-2805.

Mehta, C. R., Chandel, N. S., & Senthilkumar, T. (2014). Status, challenges and strategies for farm mechanization in India. *Agricultural Mechanization in Asia, Africa and Latin America*, *45*(4), 43-50.

Sims, B., & Kienzle, J. (2017). Sustainable agricultural mechanization for smallholders: what is it and how can we implement it?. *Agriculture*, *7*(6), 50.

Foster, A. D., & Rosenzweig, M. R. (2011). Are Indian farms too small? Mechanization, agency costs, and farm efficiency. *Unpublished Manuscript, Brown University and Yale University*.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Impacts of Long-Term Fertilizer Application on Soil Physico-Chemical and Biological Properties

Divya Kanwar, Rajsi Rajput, Harshit Kumar, Rana Kunwar Shivam Singh

Research Scholar, Division of Soil Science and Agricultural Chemistry, Dr. Bhim Rao Ambedkar University, Agra

Abstract

Soil is the foundation of sustainable agriculture, and its health determines long-term productivity, ecological balance, and food security. Fertilizers have played a crucial role in enhancing crop yields and ensuring food supply, particularly since the Green Revolution. However, their prolonged and intensive use has raised concerns regarding soil degradation, nutrient imbalances, and environmental sustainability. This paper explores the impacts of long-term fertilizer application on soil physico-chemical and biological properties. It examines how continuous use of fertilizers influences soil pH, salinity, bulk density, nutrient dynamics, and organic matter status, while also assessing changes in microbial communities, enzyme activity, and soil fauna. Evidence from long-term fertilizer experiments (LTFE) across India and global studies is presented to highlight both positive and negative outcomes. Furthermore, the paper discusses environmental consequences, such as nutrient leaching, groundwater pollution, and greenhouse gas emissions. To ensure sustainability, strategies like Integrated Nutrient Management (INM), biofertilizers, organic amendments, and precision farming are emphasized. The review concludes with research needs and policy perspectives for maintaining soil health and ensuring resilient agro-ecosystems under increasing pressure from climate change and population growth.

1. Introduction

Soil health is one of the most critical determinants of agricultural productivity and ecological sustainability. Fertilizers have been central to modern agriculture, particularly in developing countries like India, where the Green Revolution significantly increased crop yields and averted food scarcity. By supplying essential macronutrients (nitrogen, phosphorus, and potassium) and micronutrients, fertilizers have helped bridge nutrient gaps in soils depleted by continuous cultivation.

However, long-term reliance on chemical fertilizers has generated complex impacts on soil properties. Continuous application alters soil physico-chemical characteristics such as pH, electrical conductivity, organic matter content, and cation exchange capacity (CEC). Similarly, biological attributes such as microbial diversity, biomass, and enzymatic activity are affected. While fertilizers contribute positively by replenishing nutrients, their excessive and imbalanced application can cause nutrient depletion, toxicity, soil acidification, salinity, and decline in soil biological activity.

Long-term fertilizer experiments (LTFEs), initiated globally and in India (notably by the Indian Council of Agricultural Research), have generated valuable insights into these impacts. Such experiments spanning decades help understand soil processes under continuous nutrient inputs and provide strategies for sustainable fertilizer management. This paper aims to systematically review the impacts of long-term fertilizer application on soil physico-chemical and biological properties, highlight environmental consequences, and suggest strategies to ensure sustainable soil management.

2. Soil Fertility and Fertilizer Application: An Overview

2.1. Historical Perspective

The use of fertilizers dates back to ancient civilizations where organic manures and composts were used. The advent of synthetic fertilizers in the 19th and 20th centuries revolutionized agriculture. The Green Revolution in India during the 1960s highlighted the critical role of chemical fertilizers in enhancing productivity. Fertilizer consumption has since grown exponentially, with India being one of the top consumers globally.

2.2. Importance of Fertilizers in Agriculture

- They provide essential macronutrients (N, P, K) and secondary nutrients (S, Ca, Mg).
- They compensate for nutrient removal through crop harvests.

- Fertilizers contribute significantly to yield improvement and food security.

Yet, the imbalanced use of N, P, and K (with a skew towards nitrogen) has raised sustainability concerns. Long-term application often fails to replenish micronutrients and organic matter, leading to declining soil fertility.

3. Impacts on Soil Physico-Chemical Properties

3.1. Soil pH and Acidity/Alkalinity Shifts

Continuous nitrogen fertilizer application, particularly ammonium-based fertilizers, leads to soil acidification due to nitrification processes. Acidification reduces nutrient availability (e.g., phosphorus) and increases toxic elements (e.g., Al, Mn) in acidic soils. Conversely, alkaline fertilizers may raise soil pH, causing micronutrient deficiencies such as Zn, Fe, and Mn.

3.2. Electrical Conductivity and Salinity Build-Up

Long-term excessive fertilizer use, especially under irrigated conditions, increases salt accumulation, raising soil electrical conductivity (EC). Salinity stresses roots, reduces water uptake, and leads to yield decline. Fertilizer-induced sodicity also deteriorates soil structure.

3.3. Soil Structure and Bulk Density

Prolonged fertilizer use without organic amendments reduces soil organic matter (SOM), which is critical for soil aggregation. Decline in SOM increases bulk density, decreases porosity, and reduces water-holding capacity, leading to compaction and poor root growth.

3.4. Nutrient Availability and Cation Exchange Capacity (CEC)

Continuous application of fertilizers enhances available macronutrients but may cause imbalances. Excess nitrogen can leach, phosphorus can accumulate in unavailable forms, and potassium depletion is common when N and P are used disproportionately. SOM decline reduces CEC, limiting nutrient retention.

3.5. Soil Organic Matter and Carbon Sequestration

Chemical fertilizers alone cannot maintain soil organic carbon (SOC). Long-term fertilizer-only treatments show SOC depletion, whereas combined application with farmyard manure (FYM) or compost sustains SOC and improves soil resilience.

4. Impacts on Soil Chemical Properties

4.1. Macronutrient Dynamics

1. **Nitrogen (N):** Excessive N fertilization causes leaching of nitrates, acidification, and nitrous oxide emissions.
2. **Phosphorus (P):** Long-term P addition leads to fixation in insoluble forms, reducing efficiency.
3. **Potassium (K):** Continuous N and P fertilization without K depletes soil reserves, reducing yields over time.

4.2. Micronutrient Imbalances

Soils under long-term fertilizer application often show deficiencies in zinc, boron, and iron due to antagonistic interactions with macronutrients or reduced SOM.

4.3. Soil Buffering Capacity

Soils lose their natural buffering capacity against pH changes under prolonged chemical inputs, making them more vulnerable to acidification or alkalization.

5. Impacts on Soil Biological Properties

5.1. Microbial Biomass and Diversity

Soil microorganisms are highly sensitive to long-term fertilizer use. Continuous chemical fertilization often reduces microbial biomass and shifts communities toward bacteria tolerant of acidic or nutrient-rich environments, while reducing beneficial fungi and actinomycetes.

5.2. Enzyme Activities

Soil enzymes like dehydrogenase, phosphatase, and urease act as indicators of soil health. Fertilizer-only regimes often reduce their activities, reflecting declining microbial activity, whereas integrated nutrient management sustains higher enzyme levels.

5.3. Soil Fauna

Earthworms, nematodes, and other soil fauna decline under fertilizer-only regimes, particularly where acidity or salinity develops. Their reduction weakens nutrient cycling and soil structure.

6. Comparative Impacts of Fertilizer Application Regimes

Long-term studies have shown that the impacts on soil properties differ significantly depending on the type and balance of fertilizers used.

6.1. Inorganic Fertilizer-Only Regimes

- **Positive effects:** Enhance immediate nutrient availability, increase crop productivity in the short term, and maintain high yields initially.
- **Negative effects:** Soil organic matter depletion, reduced microbial activity, pH shifts, and nutrient imbalances over decades. Continuous use often results in diminishing returns, requiring ever-increasing doses.

6.2. Organic-Only Regimes

- **Positive effects:** Improve soil structure, increase microbial activity, enhance carbon sequestration, and promote sustainable fertility.
- **Negative effects:** Limited nutrient supply in intensive systems, slower nutrient release, and yield reduction compared to balanced fertilizer regimes in high-demand crops.

6.3. Integrated Nutrient Management (INM)

A combination of inorganic fertilizers with organic inputs (compost, FYM, crop residues, biofertilizers) sustains soil fertility better than either approach alone. INM maintains soil organic matter, microbial diversity, and balanced nutrient availability while achieving high yields. This regime is widely advocated as the most sustainable option for long-term productivity.

7. Environmental Consequences of Long-Term Fertilizer Application

7.1. Groundwater Contamination

Nitrate leaching from continuous nitrogen fertilizer application contaminates groundwater, posing risks to human health (e.g., methemoglobinemia or "blue baby syndrome").

7.2. Eutrophication of Water Bodies

Phosphorus and nitrogen runoff contribute to algal blooms in lakes and rivers. Eutrophication depletes dissolved oxygen, harming aquatic ecosystems.

7.3. Greenhouse Gas Emissions

Fertilizer use contributes to greenhouse gas emissions, primarily **nitrous oxide (N_2O)**, a potent gas with a global warming potential ~300 times that of CO_2. Continuous fertilizer use without mitigation strategies accelerates climate change.

7.4. Soil Degradation

Salinization, sodicity, and compaction caused by excessive fertilizer inputs degrade soils, reducing their capacity for sustainable agriculture.

8. Evidence from Long-Term Fertilizer Experiments (LTFE)

India has one of the world's most extensive LTFE networks, established by the **Indian Council of Agricultural Research (ICAR)** in 1970. These experiments, conducted across diverse agro-climatic regions, provide valuable insights:

- **Soil Organic Carbon:** Fertilizer-only plots showed SOC depletion, whereas balanced NPK + FYM plots sustained or increased SOC.
- **pH Changes:** Acidification observed in continuous ammonium-N application in humid regions, while alkaline shifts occurred in arid areas.
- **Micronutrients:** Fertilizer-only regimes led to Zn and S deficiencies over time.
- **Biological Properties:** Higher microbial biomass and enzyme activity were consistently observed under treatments combining fertilizers and organics.
- **Yield Trends:** Continuous N application alone led to yield decline after 10–15 years, while balanced NPK + organics maintained yield stability.

Example: At Rothamsted (UK), the Broadbalk experiment (initiated in 1843) revealed similar patterns: sole fertilizer plots showed soil acidification and SOC decline, whereas manure-treated plots maintained fertility and higher yields.

9. Strategies for Sustainable Fertilizer Management

9.1. Integrated Nutrient Management (INM): Combining chemical fertilizers with organics (compost, FYM, green manures, crop residues) improves nutrient use efficiency and maintains soil fertility.

9.2. Site-Specific Nutrient Management (SSNM): Tailoring fertilizer application based on soil tests, crop requirements, and local conditions prevents overuse and nutrient imbalances.

9.3. Biofertilizers and Microbial Inoculants: Use of Rhizobium, Azotobacter, Azospirillum, phosphate-solubilizing bacteria (PSB), and mycorrhizal fungi reduces chemical fertilizer demand and improves soil biological health.

9.4. Precision Agriculture Tools: Remote sensing, GIS, and sensors for real-time soil nutrient monitoring ensure efficient fertilizer use, reducing losses and environmental impacts.

9.5. Conservation Agriculture Practices: Minimum tillage, residue retention, and crop diversification enhance soil organic matter and microbial activity, counteracting adverse effects of fertilizer-only regimes.

9.6. Policy and Extension Interventions: Policies promoting balanced fertilizer use (e.g., rational NPK subsidies), strengthening soil testing infrastructure, and educating farmers about INM are essential.

10. Future Directions in Fertilizer Use and Soil Health

10.1. Climate-Smart Fertilizer Practices: Developing fertilizers that release nutrients slowly (coated urea, nano-fertilizers) reduces losses and improves nutrient uptake efficiency.

10.2. Recycling of Organic Wastes: Agro-industrial residues, urban organic wastes, and biochar offer sustainable alternatives to maintain soil fertility and reduce dependence on chemical fertilizers.

10.3. Soil Health Monitoring and Indices: Developing robust soil health cards and indices based on physico-chemical and biological indicators will help track changes under long-term fertilizer use.

10.4. Genotype × Nutrient Interaction Studies: Future crop breeding should emphasize nutrient-use efficiency to reduce fertilizer demand without compromising yield.

11. Conclusion

Long-term fertilizer application has both positive and negative consequences. While it has undoubtedly improved crop productivity and food security, excessive and imbalanced use poses threats to soil health, environmental sustainability, and future agricultural resilience.

- **Physico-chemical impacts:** Soil acidification, salinity, nutrient imbalances, and organic matter depletion.
- **Biological impacts:** Decline in microbial diversity, enzyme activity, and soil fauna.
- **Environmental consequences:** Water pollution, eutrophication, greenhouse gas emissions, and soil degradation.

Evidence from LTFEs clearly shows that integrated approaches combining fertilizers with organic inputs sustain soil fertility, crop yields, and ecological balance in the long run. Future fertilizer management must align with climate-smart agriculture, precision farming, and soil health restoration strategies to ensure food security for a growing population while safeguarding the environment.

The sustainable way forward lies not in abandoning fertilizers, but in optimizing their use through balanced, site-specific, and integrated management practices that simultaneously protect soil health and secure agricultural productivity.

References:

Bhatt, M., Singh, A. P., Singh, V., Kala, D. C., & Kumar, V. (2019). Long-term effect of organic and inorganic fertilizers on soil physico-chemical properties of a silty clay loam soil under rice-wheat cropping system in Tarai region of Uttarakhand. *Journal of Pharmacognosy and Phytochemistry*, *8*(1), 2113-2118.

Bouajila, K., & Sanaa, M. (2011). Effects of organic amendments on soil physico-chemical and biological properties. *J. Mater. Environ. Sci*, *2*(1), 485-490.

Bhatt, M. K., Labanya, R., & Joshi, H. C. (2019). Influence of long-term chemical fertilizers and organic manures on soil fertility-A review. *Universal Journal of Agricultural Research*, *7*(5), 177-188.Pahalvi, H. N., Rafiya, L., Rashid, S., Nisar, B., & Kamili, A. N. (2021). Chemical fertilizers and their impact on soil health. In *Microbiota and biofertilizers, Vol 2: Ecofriendly tools for reclamation of degraded soil environs* (pp. 1-20). Cham: Springer International Publishing.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Harnessing Mycorrhizal Fungi for Enhanced Soil Nutrient Uptake and Sustainable Crop Productivity

Palak Mehra[1], Ishaan Mahajan[2]

[1]M.Sc. (Ag.) Division of Soil Science, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu

[2]M.Sc. (Ag.) Organic Farming, Centre for Organic and Natural Farming, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu

Abstract

Sustainable agricultural production faces growing challenges due to declining soil fertility, excessive dependence on chemical fertilizers, and environmental degradation. Mycorrhizal fungi, particularly arbuscular mycorrhizal fungi (AMF), form symbiotic associations with plant roots and play a pivotal role in enhancing nutrient uptake, improving soil health, and increasing crop productivity. By extending the root surface area through extensive hyphal networks, mycorrhizae significantly improve the acquisition of phosphorus, nitrogen, and micronutrients, while simultaneously enhancing water absorption and stress tolerance. This symbiosis contributes to improved crop yield stability, soil structure, and ecosystem sustainability, thereby reducing reliance on synthetic fertilizers. With the increasing need for eco-friendly and climate-resilient agricultural practices, the application of mycorrhizal biofertilizers represents a viable strategy for nutrient management. However, large-scale adoption remains limited due to variability in field performance, storage constraints, and lack of farmer awareness. Advances in biotechnology, microbial consortia development, and integration with conservation agriculture offer new opportunities for scaling up their use. This paper provides a comprehensive assessment of mycorrhizal fungi in nutrient uptake and sustainable crop productivity, exploring mechanisms, benefits, challenges, and future prospects.

Keywords: Mycorrhizal fungi, nutrient uptake, soil fertility, biofertilizers, sustainable agriculture, crop productivity

1. Introduction

The twenty-first century agriculture is confronted with the dual challenge of producing more food to feed a rapidly growing global population while safeguarding the environment and conserving natural resources. India, with its predominantly agrarian economy, exemplifies this dilemma, where agricultural intensification has led to both increased production and severe ecological consequences. The heavy use of synthetic fertilizers and pesticides has caused soil degradation, nutrient imbalances, groundwater contamination, and greenhouse gas emissions. While fertilizers, particularly nitrogen and phosphorus-based inputs, have contributed significantly to the Green Revolution and subsequent yield gains, their long-term sustainability has been questioned.

One of the major concerns in Indian agriculture is the declining efficiency of applied nutrients. For instance, the efficiency of phosphorus fertilizers often remains below 20%, as most of the applied phosphorus gets fixed in the soil due to chemical interactions, rendering it unavailable to plants. Similarly, nitrogen fertilizers exhibit only 30–40% efficiency, with the remainder lost through volatilization, leaching, or denitrification. Such inefficiencies not only escalate the cost of cultivation for farmers but also threaten soil and environmental health. In this context, sustainable nutrient management strategies are crucial to ensure agricultural productivity without compromising ecological integrity.

Beneficial soil microorganisms have emerged as key players in addressing these challenges. Among them, mycorrhizal fungi are of particular interest due to their symbiotic association with plant roots, which improves nutrient and water uptake, enhances stress tolerance, and contributes to soil fertility. These fungi establish an intricate network of hyphae in the rhizosphere, effectively extending the plant's root system and facilitating access to nutrients beyond the depletion zone. Furthermore, their ability to solubilize and mobilize poorly available nutrients, such as phosphorus, zinc, and iron, makes them highly valuable in low-input and resource-constrained farming systems. The importance of mycorrhizal fungi in agriculture extends beyond nutrient acquisition. They contribute to soil structure stabilization by producing glomalin, a glycoprotein that enhances soil aggregation, water retention, and carbon sequestration. Additionally, their role in alleviating biotic and abiotic stresses, such as drought, salinity, and pathogen attack, underscores their significance in climate-smart agriculture. Despite these well-documented benefits, the large-scale application of mycorrhizal inoculants in India remains limited, primarily due to challenges in production, storage, distribution, and farmer adoption.

This paper aims to provide a comprehensive assessment of the role of mycorrhizal fungi in enhancing soil nutrient uptake and sustainable crop productivity. It examines their mechanisms of action, contributions to plant growth and soil health, relevance in sustainable agriculture, application strategies, challenges, and future prospects. By synthesizing current knowledge, the study highlights the potential of mycorrhizal fungi as a cornerstone of ecological intensification in agriculture.

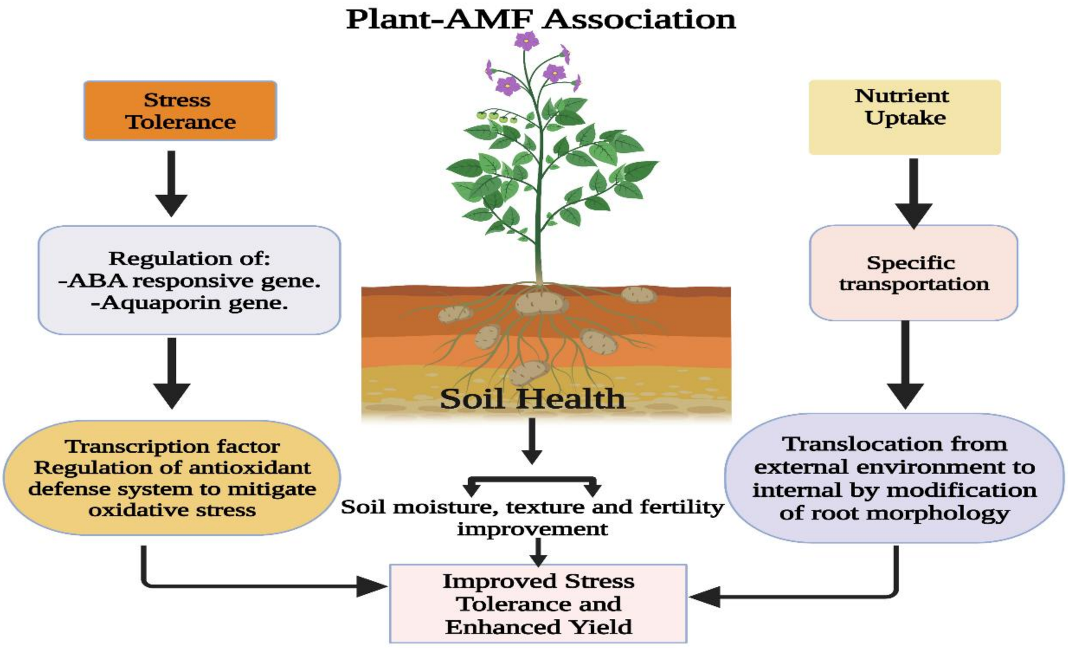


Figure 1: Arbuscular mycorrhizal fungi enhance soil fertility and nutrients uptake

2. Mycorrhizal Fungi: An Overview

Mycorrhizal fungi represent a diverse group of soil fungi that form mutualistic associations with the roots of nearly 80% of terrestrial plant species. The term “mycorrhiza” derives from the Greek words *mykes* (fungus) and *rhiza* (root), indicating the intimate relationship between plant roots and fungi. In this symbiosis, plants provide carbohydrates to the fungi, while the fungi enhance nutrient and water uptake for the host plant.

2.1. Types of Mycorrhizal Associations

Several types of mycorrhizal associations exist, each adapted to specific ecological niches and plant groups:

1. **Arbuscular Mycorrhizal Fungi (AMF):** The most common form, AMF belong to the phylum Glomeromycota and colonize the root cortex of a wide range of crops. They form structures such as arbuscules (sites of nutrient exchange) and vesicles (storage organs).
2. **Ectomycorrhizae (ECM):** Predominantly associated with forest trees like pines, oaks, and eucalypts, ECM fungi form a sheath around roots and extend hyphae into the soil.
3. **Ericoid and Orchid Mycorrhizae:** Specialized associations found in ericaceous plants (e.g., blueberries) and orchids.
4. **Other Variants:** Arbutoid and monotropoid mycorrhizae, though less common, play significant roles in specific ecosystems.

2.2. Distribution and Diversity

AMF are the most relevant to agriculture due to their association with cereals, legumes, vegetables, and fruit crops. Their diversity varies with soil type, climate, cropping system, and management practices. Conventional tillage and heavy fertilizer application often reduce AMF populations, while organic farming and reduced tillage promote their abundance.

2.3. Functional Role in Agroecosystems

Mycorrhizal fungi function as biofertilizers, bioprotectants, and soil stabilizers. They improve nutrient uptake efficiency, enhance plant growth, and increase tolerance to stress. Importantly, they serve as keystone species in the soil microbiome, contributing to ecosystem stability and resilience.

3. Mechanisms of Nutrient Uptake Enhancement

The ability of mycorrhizal fungi to enhance nutrient acquisition is central to their agricultural value. Several mechanisms are involved:

3.1. Phosphorus Uptake

Phosphorus (P) is a vital macronutrient, often limiting in Indian soils due to fixation by calcium, iron, and aluminum compounds. AMF hyphae extend beyond the root depletion zone, accessing immobile P pools and transporting them to the host plant. AMF also secrete enzymes like acid phosphatases that mobilize organic P.

3.2. Nitrogen Acquisition

Although nitrogen is relatively mobile in soil, AMF improve its uptake, particularly ammonium and organic N forms. They enhance nitrogen-use efficiency by reducing losses and facilitating transport through fungal hyphae.

3.3. Micronutrient Mobilization

AMF improve the availability of micronutrients such as zinc, copper, manganese, and iron, which are often deficient in intensively cultivated soils. This has direct implications for crop nutrition and human health.

3.4. Improved Water Absorption

The extensive hyphal network increases the soil volume explored by roots, enhancing water uptake, particularly under drought conditions. This contributes to better plant hydration and resilience.

3.5. Soil Enzyme Activity

Mycorrhizal colonization stimulates rhizosphere enzyme activities (e.g., dehydrogenase, urease, phosphatase), further promoting nutrient cycling and soil fertility.

4. Mycorrhizal Symbiosis and Plant Growth

4.1. Effects on Crop Productivity

Numerous studies have demonstrated yield increases in cereals, legumes, vegetables, and horticultural crops inoculated with AMF. For example, wheat and maize show improved grain yields, while legumes exhibit enhanced nodulation and nitrogen fixation when co-inoculated with AMF and rhizobia.

4.2. Stress Tolerance

- **Drought:** AMF improve plant water relations, stomatal regulation, and osmotic adjustment.
- **Salinity:** They reduce ion toxicity by regulating sodium and chloride uptake.
- **Heavy Metal Stress:** AMF immobilize metals like cadmium and lead in fungal tissues, reducing toxicity to plants.

4.3. Soil Structure Improvement

Glomalin, a glycoprotein secreted by AMF, promotes soil aggregation, enhances organic matter stabilization, and increases soil carbon sequestration.

4.4. Disease Suppression

AMF reduce the incidence of root pathogens (e.g., Fusarium, Phytophthora) by competing for infection sites, inducing plant defense mechanisms, and improving overall plant vigor.

5. Mycorrhiza in Sustainable Agriculture

5.1. Reduced Fertilizer Dependency

Mycorrhizal fungi enhance nutrient-use efficiency, enabling significant reductions in chemical fertilizer inputs. Studies suggest that AMF can replace 25–50% of phosphorus fertilizers without yield penalties.

5.2. Soil Fertility and Ecosystem Services

AMF contribute to nutrient cycling, soil carbon storage, and biodiversity, making them vital for long-term soil fertility.

5.3. Integration with Organic and Conservation Agriculture

Mycorrhizae thrive under organic farming, crop rotations, cover cropping, and reduced tillage systems, aligning them with sustainable practices.

5.4. Contribution to Climate-Smart Agriculture

By improving stress tolerance, nutrient efficiency, and soil carbon sequestration, AMF play a critical role in adapting to and mitigating climate change.

6. Application and Inoculation Strategies

6.1. Mycorrhizal Biofertilizers

AMF inoculants are developed as biofertilizers, containing spores, hyphae, and colonized root fragments. They are applied as seed treatments, root dips, or soil amendments.

6.2. Factors Influencing Colonization

Colonization efficiency depends on soil type, crop species, native AMF populations, and agronomic practices. Excessive fertilizer use often suppresses colonization.

6.3. Compatibility with Crops

Different crops respond variably to AMF inoculation. Legumes, maize, and horticultural crops are highly responsive, while some brassicas exhibit low colonization.

6.4. Synergistic Interactions

Co-inoculation with rhizobia, phosphate-solubilizing bacteria, and plant growth-promoting rhizobacteria (PGPR) enhances the performance of AMF.

7. Challenges and Limitations

Despite their proven benefits, several barriers limit large-scale adoption:

- **Variability in Field Performance:** Results vary with soil, climate, and crop conditions.
- **Inoculant Production and Storage:** Mass production and maintaining viable inocula for extended periods remain challenging.
- **Farmer Awareness:** Lack of knowledge about benefits and application methods reduces adoption.
- **Policy and Market Gaps:** Limited institutional support, standardization, and distribution networks hinder commercialization.

8. Future Prospects

8.1. Advances in Biotechnology

Molecular tools are improving our understanding of AMF genetics, diversity, and host interactions, enabling the development of superior inoculants.

8.2. Microbial Consortia

Combining AMF with other beneficial microbes offers synergistic effects for nutrient uptake, stress tolerance, and yield improvement.

8.3. Climate-Smart Agriculture

Mycorrhizae are critical for enhancing resilience against climate change by improving nutrient and water-use efficiency.

8.4. Policy Support

Government initiatives promoting biofertilizers, sustainable agriculture, and organic farming can facilitate large-scale adoption.

9. Conclusion and Recommendations

Mycorrhizal fungi represent a powerful natural solution to the challenges of nutrient management and sustainable crop productivity. By enhancing nutrient uptake, improving stress tolerance, and contributing to soil health, they reduce dependence on chemical fertilizers and promote ecological sustainability. However, widespread adoption requires overcoming barriers related to inoculant production, distribution, and farmer awareness.

Recommendations:

1. Strengthen research on region-specific AMF inoculants.
2. Promote farmer training and awareness programs.
3. Integrate AMF use into government soil health and fertilizer subsidy policies.
4. Encourage public–private partnerships for large-scale biofertilizer production.

5. Explore synergistic microbial consortia for holistic soil health management.

Harnessing the potential of mycorrhizal fungi is not merely an option but a necessity for sustainable agriculture in the face of rising population, resource constraints, and climate change.

References:

Wahab, A., Muhammad, M., Munir, A., Abdi, G., Zaman, W., Ayaz, A., ... & Reddy, S. P. P. (2023). Role of arbuscular mycorrhizal fungi in regulating growth, enhancing productivity, and potentially influencing ecosystems under abiotic and biotic stresses. *Plants*, *12*(17), 3102.

Fasusi, O. A., Babalola, O. O., & Adejumo, T. O. (2023). Harnessing of plant growth-promoting rhizobacteria and arbuscular mycorrhizal fungi in agroecosystem sustainability. *CABI Agriculture and Bioscience*, *4*(1), 26.

Ahmed, N., Li, J., Li, Y., Deng, L., Deng, L., Chachar, M., ... & Tu, P. (2025). Symbiotic synergy: How Arbuscular Mycorrhizal Fungi enhance nutrient uptake, stress tolerance, and soil health through molecular mechanisms and hormonal regulation. *IMA fungus*, *16*, e144989.

Rillig, M. C., Sosa-Hernández, M. A., Roy, J., Aguilar-Trigueros, C. A., Vályi, K., & Lehmann, A. (2016). Towards an integrated mycorrhizal technology: harnessing mycorrhiza for sustainable intensification in agriculture. *Frontiers in Plant Science*, *7*, 1625.

Cobb, A. B., Wilson, G. W., Goad, C. L., Bean, S. R., Kaufman, R. C., Herald, T. J., & Wilson, J. D. (2016). The role of arbuscular mycorrhizal fungi in grain production and nutrition of sorghum genotypes: Enhancing sustainability through plant-microbial partnership. *Agriculture, Ecosystems & Environment*, *233*, 432-440.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Impact of Climate Change on Agricultural Income and Livelihood Security in India: Challenges and Adaptive Strategies

[1]Gopesh Kumari, [2]Anil Singh Rawat, [3]Priyesh Ranjan

[1]Research Scholar, Department of Agricultural Economics, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan

[2]Research Scholar, Department of Agricultural Economics, Chimanbhai Patel College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar

[3]Research Scholar, Department of Agricultural Economics, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh

Abstract

Climate change has emerged as one of the most pressing challenges to agricultural sustainability and rural livelihood security worldwide. In India, where nearly half of the population depends on agriculture and allied sectors, changes in temperature, rainfall patterns, and extreme weather events directly affect crop yields, farm income, and rural well-being. This paper presents a comprehensive assessment of the impacts of climate change on Indian agriculture, with particular focus on its implications for income and livelihood security. It highlights how erratic monsoons, rising average temperatures, increasing frequency of droughts, floods, and cyclones, and the proliferation of pests and diseases have compounded risks for farmers, especially smallholders. The paper also discusses the socio-economic consequences of these changes, including income instability, indebtedness, rural poverty, and nutritional insecurity. Further, it identifies major challenges in adaptation such as technological gaps, weak institutional support, limited insurance coverage, and market volatility. Drawing upon national and international evidence, the study outlines adaptive strategies including climate-smart agriculture, crop diversification, improved irrigation management, digital technologies, and policy interventions like crop insurance and resilient infrastructure. The paper concludes that safeguarding agricultural incomes and ensuring livelihood security in the face of climate change requires a multi-pronged approach that integrates scientific innovation, effective governance, and community participation.

Keywords: Climate change, Indian agriculture, farm income, livelihood security, adaptation, climate-smart agriculture.

1. Introduction

Agriculture remains the backbone of India's economy, employing nearly 42% of the workforce and contributing significantly to food security and rural livelihoods. Despite its declining share in GDP (currently around 18%), agriculture continues to influence growth, poverty reduction, and socio-political stability. However, the sector is highly vulnerable to climate variability, given its dependence on monsoon rainfall, fragmented landholdings, and low levels of mechanization and resource efficiency.

Climate change has amplified these vulnerabilities. According to the Indian Meteorological Department (IMD), the mean annual temperature in India has risen by about 0.7°C during the 20th century, and projections suggest an increase of 1.5–2.0°C by mid-century under moderate emission scenarios. Rainfall patterns are becoming increasingly erratic, with shorter but more intense spells, uneven distribution, and delayed monsoon onset. Extreme events such as droughts, floods, cyclones, and unseasonal rainfall are now more frequent, causing significant agricultural losses.

The economic consequences are severe. Studies estimate that climate change could reduce farm incomes by 15–25% in the absence of adaptation, with rainfed areas facing income losses as high as 30%. The impacts are not uniform: small and marginal farmers, who constitute 86% of India's farming households, are disproportionately affected because they lack savings, insurance, and institutional support to withstand shocks. Women farmers, who play a critical role in food production but have limited access to land, credit, and extension, are also among the most vulnerable.

2. Climate Change and Agriculture: An Overview

2.1. Trends in Temperature and Rainfall: -India has experienced a steady rise in average surface temperatures. Heat waves, once occasional, are now more frequent and prolonged, affecting crop growth and livestock health. Rainfall variability has also intensified, with some regions facing recurrent drought (e.g., Vidarbha, Bundelkhand) while others suffer from flooding (e.g., Assam, Bihar).

2.2. Extreme Weather Events: -The frequency of cyclones in the Bay of Bengal and Arabian Sea has increased, causing widespread damage to coastal agriculture and fisheries. Erratic rainfall leads to crop failure during sowing or harvest stages, compounding risks of income loss.

2.3 Agro-Ecological Vulnerability

1. **Northwest India:** Vulnerable to water stress and heat affecting wheat and rice.
2. **Indo-Gangetic Plains:** Threatened by rising temperatures impacting wheat productivity.
3. **Rainfed Deccan Plateau:** Drought-prone, with declining groundwater reserves.
4. **Eastern India:** Frequent floods damaging rice and jute.
5. **Coastal belts:** At risk from salinity intrusion and cyclones affecting crops and fisheries.

2.4. Climate Change and Agricultural Theory

Climate change influences agriculture through biophysical (temperature, water, soil) and socio-economic channels (prices, labor markets, risk). Negative impacts often outweigh positives, such as longer growing seasons in some temperate regions, because India's agriculture is already operating close to climatic thresholds.

3. Impact of Climate Change on Agricultural Production Systems

3.1. Crop Productivity and Yield Variability

Climate models project that yields of major crops such as rice and wheat could decline by 10–40% by 2100 depending on emission pathways. Wheat, highly sensitive to heat stress during flowering, faces productivity declines in northern India. Rice yields are affected by shorter growing periods and spikelet sterility during heat waves. Pulses and oilseeds are vulnerable to moisture stress.

3.2. Water Resources and Irrigation

India's irrigation systems are under pressure from depleting groundwater reserves, especially in Punjab, Haryana, and western UP. Climate-induced variability in rainfall reduces recharge potential. Increased evapotranspiration due to higher temperatures raises water demand, exacerbating competition across agriculture, industry, and domestic use.

3.3. Soil Health and Fertility

Erratic rainfall accelerates soil erosion and nutrient depletion. Rising temperatures exacerbate organic matter decomposition, reducing soil fertility. Salinity intrusion in coastal areas and desertification in arid zones further reduce productive land availability.

3.4. Pests, Diseases, and Weeds

Climate change alters pest and disease dynamics. Warmer winters allow pests to survive longer, increasing infestation risks. For example, pink bollworm attacks in cotton and locust outbreaks are linked to climatic anomalies. Weeds also proliferate under higher CO_2 concentrations, outcompeting crops for resources.

3.5. Livestock and Fisheries

Heat stress reduces milk yield, reproductive efficiency, and survival of livestock. Fisheries are impacted by warming seas, ocean acidification, and extreme events, threatening coastal livelihoods.

4. Implications for Agricultural Income and Livelihood Security

4.1. Farm Income Instability

Unpredictable yields directly translate into unstable incomes. Smallholders, dependent on seasonal income, often face distress sales, indebtedness, and poverty traps.

4.2. Rural Employment and Migration

Reduced agricultural productivity decreases demand for rural labor, leading to underemployment and distress migration to cities. Seasonal migration often results in insecure and low-paying jobs.

4.3. Food Security and Nutrition

Declines in cereal production threaten food availability, while reduced incomes constrain food access. Climate change also affects nutritional quality; higher CO_2 concentrations reduce protein and micronutrient content in crops.

4.4. Regional and Socio-economic Disparities

Rainfed regions, home to poorer farmers, face higher risks. Women farmers, lacking land rights and access to resources, are more vulnerable. Marginalized groups (scheduled tribes and castes) often reside in ecologically fragile areas, compounding vulnerabilities.

5. Challenges in Coping with Climate Change

5.1. Technological Constraints

Adoption of climate-resilient varieties and water-saving technologies remains low due to high costs, inadequate extension, and limited awareness.

5.2. Institutional and Policy Gaps

Fragmented policies across agriculture, water, and climate reduce effectiveness. Weak coordination between central and state governments hampers implementation.

5.3. Market and Price Volatility

Global and domestic price fluctuations, coupled with climate-induced yield variability, create uncertainty. Lack of storage and processing infrastructure increases post-harvest losses.

5.4. Financial and Insurance Barriers

Crop insurance penetration is low despite schemes like PMFBY. Many farmers lack awareness or face delays in compensation. Access to credit is limited, especially for tenant farmers.

5.5. Knowledge and Extension Limitations

Farmers often rely on traditional knowledge, which is inadequate under changing climatic conditions. Extension services are under-resourced and fail to reach remote villages.

6. Adaptive Strategies for Resilient Agriculture

6.1. Climate-Smart Agriculture (CSA)

CSA integrates sustainable practices like conservation tillage, integrated nutrient management, precision farming, and agroforestry to enhance productivity, resilience, and carbon sequestration.

6.2. Crop Diversification and Livelihood Diversification

Shifting from water-intensive crops to pulses, oilseeds, and horticulture reduces risk. Diversifying livelihoods into poultry, fisheries, and agro-processing provides additional income streams.

6.3. Improved Irrigation and Water Management

Adoption of micro-irrigation (drip, sprinkler), rainwater harvesting, watershed management, and conjunctive use of surface and groundwater improves efficiency and reduces vulnerability.

6.4. Strengthening Risk Management

Expanding crop insurance coverage, improving claim settlement, and promoting weather-index insurance can cushion income shocks. Warehouse receipt systems and price stabilization funds help mitigate market risks.

6.5. ICT and Digital Tools

Mobile-based weather forecasts, early warning systems, and digital advisory platforms empower farmers with timely information for adaptive decision-making.

6.6. Community-Based Approaches

Collective action through Farmer Producer Organizations (FPOs), self-help groups, and cooperatives enhances bargaining power, resource pooling, and resilience.

7. Policy Framework and Institutional Interventions

7.1. National and State Action Plans

The **National Action Plan on Climate Change (NAPCC)** and State Action Plans outline missions for sustainable agriculture, water conservation, and energy efficiency. The **National Mission for Sustainable Agriculture (NMSA)** focuses on promoting resilient farming practices.

7.2. Government Schemes

- **Pradhan Mantri Fasal Bima Yojana (PMFBY):** Crop insurance for risk protection.

- **Pradhan Mantri Krishi Sinchai Yojana (PMKSY):** Irrigation efficiency improvement.
- **Rashtriya Krishi Vikas Yojana (RKVY):** Flexible support for climate-resilient innovations.
- **PM-KUSUM:** Promoting solar irrigation pumps to reduce energy dependence.

7.3. International Commitments

India's commitments under the Paris Agreement emphasize reducing emissions intensity and enhancing carbon sinks. Programs like the Green Climate Fund support adaptation financing.

8. Future Outlook and Research Needs

8.1. Emerging Technologies

- Stress-tolerant crop varieties (heat, drought, flood-tolerant).
- Precision agriculture using drones, sensors, and AI.
- Climate-resilient livestock breeds.

8.2. Research Priorities

- Long-term impact studies on nutrition and health.
- Region-specific vulnerability assessments.
- Socio-economic studies on gender and equity impacts.

8.3 Role of Public–Private Partnerships

PPP models can accelerate investment in climate-smart technologies, insurance products, and market infrastructure.

9. Conclusion and Recommendations

Climate change poses a severe threat to Indian agriculture, directly undermining farm incomes and rural livelihood security. The challenges—ranging from declining productivity and income instability to food insecurity and regional disparities—are complex and interlinked. While multiple adaptation strategies exist, their large-scale adoption requires enabling policies, financial support, and institutional innovations.

Key Recommendations:

1. Promote **climate-smart agriculture** and region-specific resilient technologies.
2. Strengthen **irrigation efficiency** and sustainable water management.
3. Expand and reform **crop insurance schemes** to ensure timely compensation.
4. Support **FPOs, cooperatives, and women farmers** to enhance inclusivity.
5. Invest in **digital tools, weather forecasting, and extension services**.
6. Enhance convergence between national and state policies for coherent action.
7. Encourage **PPP models** for scaling up resilient infrastructure and technologies.

In conclusion, securing agricultural incomes and livelihood security under climate change requires an integrated approach combining **science, policy, and community action**. By adopting adaptive strategies and supportive policies, India can build a resilient agricultural sector capable of sustaining farmers' welfare and national food security in the decades ahead.

References:

Sarkar, A., Dasgupta, A., & Sensarma, S. R. (2019). Climate change and food security in India: adaptation strategies and major challenges. In *Sustainable Solutions for Food Security: Combating Climate Change by Adaptation* (pp. 497-520). Cham: Springer International Publishing.

Dey, S., Singh, P. K., Abbhishek, K., Singh, A., & Chander, G. (2024). Climate-resilient agricultural ploys can improve livelihood and food security in Eastern India. *Environment, Development and Sustainability*, *26*(6), 13979-14002.

Verma, S., & Sudan, F. K. (2021). Impact of climate change on marginal and small farmers' livelihood and their adaptation strategies-a review. *Regional Economic Development Research*, 96-112.

Pathak, H. (2023). Impact, adaptation, and mitigation of climate change in Indian agriculture. *Environmental Monitoring and Assessment*, *195*(1), 52.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Strengthening Agricultural Extension through Farmer Producer Organizations (FPOs): A Pathway to Collective Empowerment

Orinkeith D S, Ajay Kumar Patidar, Sanskriti Shivhare

M.Sc. (Ag), Agricultural Extension Education, Rajmata Vijayraje Scindia Krishi Vishvavidhyalay, Gwalior

1. Introduction

Agriculture has historically been the backbone of India's rural economy, providing livelihoods to more than half of its population and contributing around 17–18% to the country's Gross Domestic Product (GDP). The sector is characterized by a large number of small and marginal farmers—constituting over 85% of the farming community—who cultivate fragmented and resource-constrained holdings. These farmers face structural challenges such as high input costs, low productivity, lack of access to quality seeds and technologies, weak bargaining power, and vulnerability to climatic and market risks.

Agricultural extension, defined as the system of delivering knowledge, technologies, and innovations to farmers, is pivotal for addressing these challenges. Traditionally, extension in India has been driven by public institutions, with models such as the Training and Visit (T&V) system, Krishi Vigyan Kendras (KVKs), and state agricultural universities playing critical roles in promoting Green Revolution technologies. While these approaches succeeded in boosting cereal production, they have been less effective in addressing the contemporary needs of diversified, market-oriented, and climate-stressed agriculture.

Farmer Producer Organizations (FPOs) have emerged as institutional innovations that hold promise for bridging the gaps in agricultural extension. As farmer-owned collectives, FPOs enable smallholders to pool resources, access credit, procure inputs at competitive prices, market their produce collectively, and build resilience through social capital. By functioning as intermediaries between farmers, markets, and extension agencies, FPOs can make agricultural extension more demand-driven, inclusive, and sustainable. This research paper explores the role of FPOs in strengthening agricultural extension and advancing collective empowerment. It draws upon theoretical frameworks, empirical evidence, and case studies from India and abroad to analyze how FPOs are redefining extension services. The paper argues that integrating FPOs into extension systems is a strategic pathway to empower farmers socially, economically, and politically, while fostering inclusive rural development.

2. Agricultural Extension: Current Challenges and Opportunities

2.1. Evolution of Agricultural Extension in India

Extension in India has evolved from colonial-era advisory services to post-independence institution-building. The Community Development Programme (1952) marked the beginning of formal extension, followed by the Training and Visit (T&V) system introduced with World Bank support in the 1970s. Later, KVKs, ATMA (Agricultural Technology Management Agency), and ICT-enabled platforms expanded outreach.

Despite this evolution, extension remains limited in coverage and relevance. According to the National Sample Survey Office (NSSO, 2013), only 40% of Indian farmers had access to formal extension services, reflecting significant gaps in inclusivity.

2.2. Persistent Challenges

1. **Fragmented Outreach**: Extension staff-to-farmer ratio remains very low, with one extension worker often serving thousands of farmers.
2. **Technology Adoption Gap**: While improved seeds, precision farming tools, and digital advisory exist, their adoption is slow due to poor last-mile delivery.
3. **Weak Market Orientation**: Most extension models emphasize production technologies, neglecting marketing, value addition, and post-harvest aspects.
4. **Social Exclusion**: Women, youth, and marginalized farmers often remain outside the purview of formal extension.

5. **Low Investment**: India spends less than 0.7% of its agricultural GDP on extension, compared to over 2% in developed nations.

2.3. Emerging Opportunities

1. **ICT Integration**: Mobile phones, digital platforms, and apps (e.g., Kisan Call Centers, mKisan) are enabling real-time advisories.
2. **Public-Private Partnerships**: Agribusiness firms are increasingly partnering with governments to deliver extension.
3. **Community-Based Models**: Collectives like FPOs, SHGs, and cooperatives are demonstrating grassroots-driven extension approaches.

3. Farmer Producer Organizations (FPOs): Conceptual Framework

3.1. Definition and Characteristics

An FPO is a collective of primary producers—farmers, milk producers, fishermen, rural artisans—who come together to form an organization that is owned and managed by them. In India, most FPOs are registered as Producer Companies under the Companies Act, 1956 (amended 2013), though some are registered under Cooperative Acts or Societies Acts.

Key features include:

- Voluntary membership.
- Democratic governance with farmer-elected boards.
- Focus on both economic and social objectives.
- Linkages with financial institutions, markets, and government schemes.

3.2. Objectives of FPOs

1. Enhance members' incomes by reducing costs and improving market access.
2. Facilitate adoption of improved technologies through extension and training.
3. Aggregate small farmers' produce to achieve economies of scale.
4. Provide input and output services such as procurement, processing, storage, and marketing.
5. Build farmers' capacity for decision-making and collective action.

3.3. Government Support and Policy Framework

1. **SFAC (Small Farmers' Agribusiness Consortium)**: Pioneer in promoting FPOs in India.
2. **NABARD**: Provides financial and technical support to Producer Organizations.
3. **10,000 FPO Scheme (2020–2030)**: Central Government initiative targeting the formation and promotion of 10,000 FPOs with handholding support for 5 years.
4. **State-Level Programs**: Andhra Pradesh's Rythu Sadhikara Samstha, Madhya Pradesh's Cluster FPOs, and Maharashtra's grape cooperatives.

4. Role of FPOs in Strengthening Agricultural Extension

4.1. FPOs as Knowledge Brokers

FPOs act as conduits between farmers and research institutions. They identify members' needs, communicate them to extension agencies, and ensure dissemination of customized advisories.

4.2. Capacity Building

FPOs organize training on:

1. Improved seed and input management.
2. Integrated pest management and soil health practices.
3. Organic and natural farming techniques.
4. Climate-smart agriculture and resource-use efficiency.

4.3. Facilitating Technology Adoption: By procuring machinery collectively (e.g., tractors, harvesters, drip irrigation kits), FPOs make technologies affordable. They also facilitate demonstrations and pilot trials that increase farmer confidence in innovations.

4.4. Market-Oriented Extension: Unlike traditional extension that ends at harvest, FPOs emphasize **end-to-end value chains**: crop planning, quality standards, grading, packaging, branding, and direct marketing.

4.5. Farmer-to-Farmer Extension: Through regular meetings, exposure visits, and peer learning, farmers exchange best practices. Social networks within FPOs accelerate diffusion of innovations.

5. FPOs as Catalysts for Collective Empowerment

5.1. Economic Empowerment

- Collective procurement reduces input costs by 15–20%.
- Aggregated sales increase bargaining power, yielding higher farm-gate prices.
- Access to institutional credit improves investment in productivity-enhancing technologies.

5.2. Social Empowerment

- Inclusion of marginalized groups, women, and youth.
- Leadership opportunities at grassroots levels.
- Community resilience through shared resources and solidarity.

5.3. Political Empowerment

- FPOs provide collective representation in government consultations.
- Enhance farmers' ability to influence agricultural policies.
- Strengthen rural democracy through participatory decision-making.

6. Case Studies and Best Practices

6.1. MahaGrapes (Maharashtra): A federation of grape-grower cooperatives that linked small farmers to export markets. Through collective extension support, farmers adopted international quality standards, improving export competitiveness.

6.2. Sahyadri Farms Producer Company (Maharashtra): India's largest FPO with over 15,000 farmer-members. Provides integrated services—input supply, extension, processing, and marketing. Its extension wing focuses on Good Agricultural Practices (GAPs), residue-free cultivation, and sustainable farming.

6.3. Kerala Vegetable FPOs: Government-supported vegetable FPOs have enhanced local food security by promoting organic farming, community seed banks, and ICT-based extension.

6.4. Dairy Cooperatives in Gujarat (Amul Model): While not formally termed as FPOs, dairy cooperatives serve as precursors. They provide veterinary extension, feed support, and marketing, demonstrating how collective action sustains empowerment.

6.5. International Best Practices

1. **Kenya**: Coffee and dairy cooperatives strengthen technology adoption and access to markets.
2. **Philippines**: Rice farmer cooperatives support mechanization and extension in partnership with government.
3. **Ethiopia**: Farmer cooperatives function as extension agents, increasing fertilizer adoption.

7. Challenges in Integrating FPOs with Extension Services

1. Weak governance structures and lack of professional management.
2. Limited working capital and overdependence on external funding.
3. Compliance burdens under legal and taxation frameworks.
4. Lack of trained extension staff within FPOs.
5. Sustainability concerns—many FPOs dissolve after initial support ends.
6. Unequal participation, with elite capture sometimes sidelining marginal farmers.

8. Strategies for Strengthening Extension through FPOs

8.1. Policy Support

- Simplify legal compliances.
- Ensure long-term handholding by implementing agencies.
- Provide start-up capital and working capital assistance.

8.2. Capacity Development

- Train FPO leaders in extension management, ICT, and agribusiness.
- Establish Extension Resource Centers within federations of FPOs.

8.3. Leveraging ICT

- Digital platforms like e-NAM, mKisan, and WhatsApp groups can enhance advisories.
- AI-based crop monitoring tools can be integrated into FPO systems.

8.4. Public-Private Partnerships

- Agribusiness companies can provide market intelligence.
- NGOs can assist with social mobilization and capacity building.

8.5 Business Model Innovation

- FPOs should diversify into seed production, custom hiring centers, food processing, and branding.
- Strengthen vertical integration with value chains.

9. Future Prospects and Research Needs

1. **Climate-Smart Agriculture**: FPOs can promote resilient practices such as water-efficient irrigation, agroforestry, and crop diversification.
2. **Gender Inclusion**: Women-led FPOs can empower female farmers and ensure gender-sensitive extension.
3. **Youth Engagement**: FPOs can attract rural youth into agri-business through innovation, start-ups, and digital agriculture.
4. **Global Linkages**: Indian FPOs can learn from international cooperative experiences in Europe and Africa.
5. **Research Needs**:
   - Impact assessment of FPOs on technology adoption and farm productivity.
   - Comparative studies of FPO vs. cooperative extension models.
   - Role of ICT and artificial intelligence in scaling FPO-led extension.

10. Conclusion

FPOs represent a paradigm shift in agricultural extension, moving from **top-down dissemination** to **bottom-up, demand-driven models**. By integrating knowledge, technology, markets, and community participation, FPOs address the long-standing limitations of extension in India. They serve as vehicles of collective empowerment, enabling smallholders to achieve economies of scale, improve incomes, and enhance social capital.

Challenges related to governance, finance, and sustainability must be addressed through targeted policies, capacity-building, and innovative partnerships. With strong institutional support, FPOs can emerge as **pillars of rural transformation**, ensuring that agricultural extension is inclusive, resilient, and future-ready.

References:

Ghosh, A., & Ghosh, A. (2023). Farmer Producer Organizations (FPOs): An emerging way of Strengthening Agricultural Sector. *Indian Farmer*, *10*(6).

Mercoiret, M. R., & Mfou'ou, J. M. (2006, October). Rural Producer Organizations (RPOs), empowerment of farmers and results of collective action. In *Paris Workshop on Rural Producer Organizations, World Bank* (pp. 30-31).

Nikam, V., Singh, P., Ashok, A., & Kumar, S. (2019). Farmer producer organisations: Innovative institutions for upliftment of small farmers. *The Indian Journal of Agricultural Sciences*, *89*(9), 1383-1392.

Khan*, M. A., Pratap, J., Siddique, R. A., & Gedam, P. M. (2020). Farmers producer organization (FPO): empowering Indian farming community.

Krishna, D. K. (2018). Farmer producer organizations: Implications for agricultural extension. *Agriculture Extension Journal*.

Biswas, P., Kumar, A., Kumari, S. S., Pathak, S., & Ahmad, N. (2025). The Role of Farmer Producer Organizations (FPOs) in Revamping Indian Agriculture Landscape. *Journal of Scientific Research and Reports*, *31*(3), 490-506.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Linking Research, Extension, and Farmers: A Triangular Framework for Accelerating Innovation Dissemination in Agriculture

Bhanita Baruah[1], Gottimukkula Sree Pooja[2], Apurba Baruah[3], Saithala Mounika[4], Siddhartha Sankar Saikia[5]

[1]PhD Scholar, School of Social Sciences, CPGS-CAU, Umiam, Meghalaya, India
[2]PhD Scholar, Department of Agricultural Extension Education, Professor Jayashankar Telangana Agricultural University, Hyderabad-500030, India
[3]Young Professional -II, ATARI, Guwahati, Assam
[4]PhD Scholar, Department of Agronomy, Professor Jayashankar Telangana Agricultural University, Hyderabad-500030, India
[5]Agricultural Development Officer, ADO, Dhemaji, Assam

Abstract

Agricultural innovation has been a cornerstone of enhancing productivity, food security, and rural livelihoods. However, the adoption of research-generated technologies by farmers has often been slow due to fragmented linkages between research institutions, extension services, and farming communities. To address this gap, a triangular framework linking **Research–Extension–Farmers (REF)** is essential for accelerating the dissemination of innovations. This framework positions researchers as technology developers, extension workers as mediators and knowledge translators, and farmers as active experimenters and adopters of new practices. By creating strong feedback loops, the triangular approach ensures that innovations are demand-driven, context-specific, and field-validated.

This paper critically examines the role of research institutions, extension systems, and farmers within this triangular framework. It highlights the contributions and limitations of each component, the role of ICTs and digital platforms in strengthening linkages, and the benefits of a participatory, multi-stakeholder model. Challenges such as institutional silos, low digital literacy, inadequate resources, and poor coordination are also discussed. Policy strategies to strengthen the REF framework, including promoting farmer-led innovation, participatory research, and digital extension systems, are explored. The study concludes that linking research, extension, and farmers in a triangular framework is not only crucial for faster technology dissemination but also for building inclusive, resilient, and sustainable agricultural systems. This paradigm shift from top-down knowledge transfer to interactive, participatory knowledge exchange can revolutionize agricultural development in rural India and beyond.

1. Introduction

Agriculture remains the backbone of rural economies, particularly in countries like India, where nearly half the population depends on farming for their livelihoods. Over the past decades, agricultural research has contributed significantly to food security through the development of high-yielding varieties, improved management practices, and innovative technologies. However, despite these scientific breakthroughs, the adoption rate of new technologies at the farm level remains uneven and often slow. Many farmers, especially smallholders, continue to rely on traditional methods that limit productivity and resilience.

One of the primary reasons for this gap between **scientific innovation and on-farm adoption** is the weak linkage between research, extension services, and farming communities. While researchers develop advanced technologies, they often fail to consider socio-economic realities, local contexts, and farmers' practical knowledge. Extension services, which act as a bridge between scientists and farmers, are frequently under-resourced, fragmented, and unable to reach large numbers of smallholders. Farmers, on the other hand, are sometimes treated as passive recipients of knowledge rather than active contributors to the innovation process.

To overcome these barriers, the need for a **triangular framework of Research–Extension–Farmers (REF)** has emerged as a critical strategy for strengthening agricultural innovation systems.

2. Conceptual Basis of the Triangular Framework

The agricultural knowledge and innovation system has traditionally been characterized by a **linear model of technology transfer** in which research institutions developed innovations, extension services disseminated them, and farmers adopted them. This "lab-to-land" model, while effective in the Green Revolution era, had inherent limitations. It assumed farmers to be passive recipients of technology, ignored local knowledge systems, and created weak feedback mechanisms. Over time, it became evident that such a unidirectional approach often resulted in poor adoption rates, mismatches between research outputs and farmers' needs, and a lack of contextual adaptation.

The triangular framework of **Research–Extension–Farmers (REF)** emerged as a corrective mechanism to these limitations. Unlike the linear model, the triangular approach promotes **dynamic, multidirectional linkages** among researchers, extension workers, and farmers. Each stakeholder plays a distinct but complementary role:

1. **Research Institutions** – Universities, agricultural research centers, and private R&D entities act as the generators of knowledge, innovations, and technologies. However, their work needs field validation and refinement to suit local conditions.
2. **Extension Systems** – Extension agents, Krishi Vigyan Kendras (KVKs), NGOs, and digital platforms act as intermediaries who interpret, simplify, and deliver scientific knowledge in farmer-friendly formats. They also collect feedback from farmers and channel it back to researchers.
3. **Farmers** – Farmers serve not only as adopters but also as co-creators of knowledge. Their experiential learning, indigenous practices, and feedback are invaluable for making technologies practical and scalable.

The conceptual foundation of the triangular framework is built upon three key principles:

1. **Participatory Knowledge Exchange** – Recognizing that farmers' insights and indigenous knowledge are as important as scientific innovations.
2. **Two-Way Communication** – Creating a feedback loop where farmers influence research priorities and research outcomes are field-tested with farmer participation.
3. **Systemic Integration** – Ensuring that innovation dissemination is not fragmented but holistic, addressing technical, socio-economic, and cultural dimensions.

3. Components of the Triangular Framework

The effectiveness of the triangular framework depends on the synergy among its three key components—**Research, Extension, and Farmers**. Each plays a vital role in innovation generation, dissemination, and adoption.

3.1. Role of Research Institutions

Research institutions are the backbone of agricultural innovation. They generate scientific knowledge, develop crop varieties, design machinery, and devise management practices. However, challenges arise when these innovations are not aligned with farmers' realities. The triangular framework compels research bodies to:

1. Conduct demand-driven research by aligning with farmers' needs.
2. Engage farmers in on-farm trials and participatory breeding programs.
3. Collaborate with extension workers to design dissemination strategies.
4. Simplify technical outputs into farmer-friendly packages of practices.

This ensures that scientific advancements are not confined to laboratories but translated into practical solutions.

3.2. Role of Extension Systems

Extension systems serve as the **connecting bridge** between researchers and farmers. Their responsibilities include technology dissemination, capacity building, demonstration of practices, and feedback collection. In the triangular model, their role expands to:

1. Knowledge translation – simplifying complex research outputs.
2. Capacity building – training farmers through demonstrations, workshops, and field schools.
3. Feedback mechanism – providing researchers with field-level insights on technology performance.
4. Policy advocacy – conveying farmers' challenges and constraints to decision-makers.

With the integration of ICTs, extension systems now have the potential to reach millions of farmers instantly, overcoming limitations of manpower and geography.

3.3. Role of Farmers

Farmers are at the heart of the triangular framework. Unlike the linear model, they are no longer considered passive adopters but **active partners**. Their responsibilities include:

1. Participatory experimentation – testing new varieties, practices, and machinery under local conditions.
2. Providing feedback – offering insights on practicality, cost-effectiveness, and cultural acceptability.
3. Knowledge sharing – spreading innovations among peer farmers through social networks.
4. Driving research priorities – influencing research agendas based on ground realities.

By empowering farmers in decision-making, the triangular model ensures inclusivity and relevance of innovations.

4. The Role of ICT and Digital Tools in Strengthening the REF Framework

The 21st century has witnessed the rapid diffusion of **Information and Communication Technologies (ICTs)** into every aspect of human activity, and agriculture is no exception. In rural India, where literacy levels are often low and traditional extension systems are constrained by limited manpower, ICTs have emerged as **transformative enablers** for linking research, extension, and farmers more efficiently. The triangular framework of Research–Extension–Farmers (REF) has been significantly strengthened by the adoption of digital tools that create **two-way, real-time communication channels** and facilitate the **scaling up of innovations**.

4.1. Digital Platforms as Innovation Gateways

Mobile phones, internet-based platforms, and mobile applications are now serving as **virtual extension agents**. They provide farmers with timely information on weather, market prices, input availability, pest and disease alerts, and government schemes. Many platforms also allow farmers to interact directly with scientists or extension officers, thus eliminating long delays in communication.

Examples include:

- **Mobile advisory services** that send SMS or voice messages in local languages.
- **Smartphone applications** offering videos, infographics, and audio guides for illiterate farmers.
- **Interactive websites and digital libraries** hosting knowledge repositories accessible to extension officers and farmer organizations.

These platforms have essentially **shrunk the distance between research institutions and farmers**, making it easier to deliver precise, localized advice.

4.2. Social Media for Farmer Engagement

Social media platforms such as WhatsApp, Facebook, and YouTube have become informal yet powerful tools of agricultural extension. Farmer groups often share experiences, photos of pest outbreaks, or success stories of new crop varieties. Extension officers and researchers participate in these groups, providing on-the-spot solutions and creating trust-based relationships. This has democratized knowledge transfer by ensuring that farmers are **no longer dependent solely on formal extension channels**.

4.3. Artificial Intelligence and Data Analytics

Artificial Intelligence (AI) and data analytics are now providing **personalized advisories** to farmers. By analyzing soil health data, weather forecasts, and crop conditions through satellite imagery, AI-driven platforms can recommend the exact dosage of fertilizer, irrigation schedules, or pest management practices. Such innovations bridge the gap between high-end scientific research and grassroots farming needs.

- **AI-based pest detection apps** allow farmers to take a photo of their crop and instantly receive a diagnosis and treatment options.
- **Predictive analytics** help extension systems anticipate outbreaks of pests or diseases, enabling proactive dissemination of solutions.
- **Big data** integration provides policymakers with insights into adoption patterns, regional constraints, and success rates of new technologies.

4.4. E-Learning and Capacity Building

Digital tools have also revolutionized **capacity-building programs**. Virtual training sessions, webinars, and Massive Open Online Courses (MOOCs) allow farmers and extension workers to access high-quality training without leaving their villages. Demonstration videos and interactive modules break down complex research findings into easy-to-understand practices.

This is particularly valuable for **women farmers and youth**, who may have restricted mobility but can now access training through their mobile phones. Thus, ICTs are not only strengthening the REF linkages but also **making them inclusive and equitable**.

4.5. Digital Feedback Loops

A crucial advantage of ICTs is the creation of **digital feedback mechanisms**. Farmers can now share their experiences, challenges, and results with researchers in real-time. Extension systems act as curators of this feedback, aggregating farmer responses and transmitting them to research institutions. Researchers can then refine their innovations or design location-specific versions of technologies. This has transformed the innovation process into a **dynamic, adaptive cycle** rather than a static one.

5. Benefits of the Triangular Framework for Innovation Dissemination

The adoption of the triangular REF framework, reinforced by digital tools, has led to multiple benefits for the agricultural sector in India and other developing countries. These benefits can be classified into **technological, economic, social, and environmental** dimensions.

5.1. Technological Benefits

- **Faster Dissemination** – Technologies developed in research stations now reach farmers at an unprecedented pace.
- **Localized Solutions** – Farmers' feedback ensures that innovations are adapted to specific agro-climatic zones.
- **Higher Adoption Rates** – When farmers are involved in the development process, their trust in the technology increases, leading to wider adoption.
- **Innovation Co-Creation** – Collaborative trials allow farmers to customize technologies to their needs.

5.2. Economic Benefits

- **Increased Productivity** – Access to modern innovations enhances crop yields and livestock productivity.
- **Reduced Costs** – Digital advisories optimize input use, reducing wastage and unnecessary expenses.
- **Market Linkages** – Digital platforms connect farmers to buyers, reducing dependence on middlemen and improving profitability.
- **Entrepreneurship Opportunities** – Farmers trained in digital tools often become local service providers, generating rural employment.

5.3. Social Benefits

- **Farmer Empowerment** – Involving farmers as decision-makers builds their confidence and leadership skills.
- **Inclusivity** – Women, youth, and smallholders benefit from easier access to knowledge and resources.
- **Community Building** – Digital groups foster peer-to-peer learning and collective problem-solving.
- **Improved Literacy** – Regular interaction with ICT platforms indirectly enhances digital and functional literacy among farmers.

5.4. Environmental Benefits

- **Sustainable Practices** – Advisory systems promote organic farming, integrated pest management, and climate-smart practices.
- **Reduced Resource Wastage** – Precision advisories minimize excessive use of fertilizers and pesticides.
- **Climate Resilience** – Farmers receive early warnings about weather extremes, enabling preparedness.
- **Biodiversity Conservation** – Promotion of local varieties and ecological practices helps sustain biodiversity.

6. Strategies and pathways to operationalise the REF triangle

1. Institutional reforms and coordination
2. Strengthening extension capacity
3. Engaging farmers as partners
4. Digital integration with equity safeguards
5. Financing and sustainability
6. Monitoring, evaluation and adaptive learning

7. Policy recommendations

To mainstream the REF approach and enable systemic change, policy action is needed at multiple levels.

1. **National REF strategy:** Governments should articulate a national REF strategy that outlines roles, financing mechanisms, coordination platforms and digital governance norms.
2. **Fund participatory research:** Allocate dedicated funding for participatory on-farm research, farmer breeding programs and co-innovation grants.
3. **Invest in extension:** Increase public financing for extension, including digital infrastructure, training and decentralized funds for local adaptation.
4. **Support FPOs and collectives:** Provide institutional support, concessional finance and capacity building for FPOs to function as local innovation hubs.
5. **Enable data governance:** Enact policies that protect farmer data, ensure transparency over data use and promote equitable data benefit sharing.
6. **Promote inclusive access:** Subsidize digital access for marginalized groups and invest in local language content and female-centric outreach programs.

8. Conclusion

The Research–Extension–Farmers triangular framework reframes innovation dissemination as a relational and iterative process of co-creation rather than a unidirectional transfer. When each node- research, extension, and farmers fulfills complementary roles and robust enabling mechanisms link them, the speed, relevance and equity of technology adoption improves markedly. Digital technologies amplify these linkages, but they must be integrated thoughtfully with in-person facilitation and strong governance to avoid exacerbating inequalities. Operationalizing the REF framework at scale demands institutional reforms, capacity investments, inclusive financing models and a commitment to participatory research and local adaptation. Farmer collectives and local intermediaries are indispensable for localizing innovation and ensuring sustainability.

Ultimately, the REF triangle is not merely a technocratic device; it is a democratic architecture that recognizes farmers as active agents of innovation. Strengthening this triangle will be central to achieving resilient, productive and inclusive agricultural systems in the face of climate change, market volatility and socio-economic pressures.

References:

Prajapati, C. S., Priya, N. K., Bishnoi, S., Vishwakarma, S. K., Buvaneswari, K., Shastri, S., ... & Jadhav, A. (2025). The role of participatory approaches in modern agricultural extension: bridging knowledge gaps for sustainable farming practices. *Journal of Experimental Agriculture International*, *47*(2), 204-222.

Becerra-Encinales, J. F., Bernal-Hernandez, P., Beltrán-Giraldo, J. A., Cooman, A. P., Reyes, L. H., & Cruz, J. C. (2024). Agricultural extension for adopting technological practices in developing countries: A scoping review of barriers and dimensions. *Sustainability*, *16*(9), 3555.

Chintakindi¹, S., Muneer, S., & Kemekar, P. AGRICULTURAL EXTENSION SERVICES AND KNOWLEDGE TRANSFER. *An Edited Anthology*, 180.

Kingiri, A. N. (2013). A review of innovation systems framework as a tool for gendering agricultural innovations: exploring gender learning and system empowerment. *The Journal of Agricultural Education and Extension*, *19*(5), 521-541.

Anandajayasekeram, P., & Gebremedhin, B. (2009). *Integrating innovation systems perspective and value chain analysis in agricultural research for development: Implications and challenges* (Vol. 16). ILRI (aka ILCA and ILRAD).

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

WTO and Indian Agriculture: A Comprehensive Economic Assessment of Trade Liberalization and Its Policy Implications

[1]Anil Singh Rawat, [2]Gopesh Kumari, [3]Priyesh Ranjan

[1]Research Scholar, Department of Agricultural Economics, Chimanbhai Patel College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar
[2]Research Scholar, Department of Agricultural Economics, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan
[3]Research Scholar, Department of Agricultural Economics, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh

Abstract

The World Trade Organization (WTO) has played a pivotal role in reshaping the global agricultural landscape and its influence on Indian agriculture has been profound. Since India became a member in 1995, trade liberalization under the WTO framework has created new opportunities for exports, especially in basmati rice, cotton, spices, horticultural crops and marine products, while simultaneously exposing domestic producers to import surges, price volatility and stricter quality standards. This paper provides a comprehensive economic assessment of these shifts by analyzing the impacts of the Agreement on Agriculture (AoA), sanitary and phytosanitary (SPS) measures, domestic support policies and intellectual property rights on Indian agriculture. The study highlights that although liberalization has expanded India's agricultural trade, its benefits remain uneven due to structural challenges such as small farm size, low productivity, weak infrastructure, and high compliance costs. The paper emphasizes the dual challenge of safeguarding food security and farmer welfare while pursuing export competitiveness. It argues that India's agricultural strategy should prioritize WTO-consistent support mechanisms, investment in climate-resilient productivity and inclusive value-chain development through Farmer Producer Organizations (FPOs) and digital platforms. By aligning trade liberalization with sustainable development goals, India can transform its agricultural sector into a globally competitive yet socially equitable system.

Keywords: WTO, Indian agriculture, trade liberalization, Agreement on Agriculture, SPS, food security, policy reforms

1. Introduction

Agriculture remains foundational to India's economy and society, providing livelihoods for a large share of the workforce and underpinning food and nutritional security. Since India's accession to the WTO in 1995, agricultural policy has been reframed within multilateral disciplines, complemented by India's cautious tariff liberalization and episodic export controls for food staples. The resulting policy mix-market-led reforms tempered by food security imperatives-has generated sectoral winners and losers and tested the state's capacity to stabilize prices while integrating with global markets.

This paper offers a comprehensive economic assessment of how WTO disciplines and the broader trade-liberalization process have interacted with India's structural realities: small and fragmented holdings, variable irrigation and infrastructure, diverse Agro-ecologies, and persistent productivity gaps. Rather than adjudicating liberalization as good or bad, we map where and how it has worked, for whom, and under what policy settings and draw policy implications for the next phase of reforms.

Objectives:

1. Explain the WTO agricultural framework and its relevance to India.
2. Analyze trade, price and welfare outcomes across key commodities.
3. Examine distributional and regional impacts, including gendered effects.
4. Derive policy recommendations consistent with WTO rules and India's development priorities.

2. WTO Agricultural Rules and Their Relevance to India

2.1. The Agreement on Agriculture (AoA)

The AoA organizes commitments under three pillars:

1. **Market Access:** Conversion of quantitative restrictions to tariffs ("tariffication"), binding of tariffs, and disciplines on tariff-rate quotas.
2. **Domestic Support:** Classification of subsidies into **Amber Box** (trade-distorting, subject to Aggregate Measurement of Support—AMS), **Blue Box** (production-limiting programs), and **Green Box** (minimally trade-distorting, exempt). Developing countries also have **de minimis** allowances.
3. **Export Competition:** Progressive elimination of export subsidies and disciplines on export finance and state trading enterprises.

2.2. SPS/TBT and TRIPS Interfaces

1. **SPS/TBT:** While the AoA addresses border measures, **Sanitary and Phytosanitary (SPS)** and **Technical Barriers to Trade (TBT)** agreements govern food safety and quality standards, labeling, and conformity assessment—areas increasingly decisive for market access.
2. **TRIPS:** Intellectual property rules intersect agriculture through plant variety protection, seed systems and geographical indications (GIs), with implications for innovation, farmer rights and export branding.

2.3. India's Policy Anchors under the WTO

India's approach has combined relatively high but bound tariffs (with flexibility to adjust applied rates), public procurement and **Minimum Support Prices (MSP)** for staples, targeted input subsidies (fertilizer, irrigation, power), public stockholding for food security, and selective export restrictions to manage domestic prices. Compatibility with WTO rules hinges on subsidy classification, AMS calculations, valuation of support relative to an external reference price and the treatment of public stockholding.

3. Indian Agriculture in the Pre- and Post-WTO Era

3.1 Pre-WTO Baseline

Before 1995, the policy regime featured import controls, state trading, licensing and a strong emphasis on food self-sufficiency. Productivity gains from the Green Revolution were concentrated in irrigated cereals, while rainfed areas lagged. Trade was modest, with limited integration into global value chains for high-value products.

3.2 Post-WTO Transitions

Post-1995, India progressively rationalized tariffs and moved from non-tariff barriers to tariff-based protection, while retaining policy space for food staples. Key shifts include:

1. **Export Dynamism** in basmati rice, cotton, spices, and marine products, supported by private investment, quality upgrading and GI branding.
2. **Import Exposure** in edible oils and, at times, pulses, due to domestic demand outpacing supply and relative price differentials.
3. **Diversification** toward horticulture and animal products, with rising roles for cold chains and food processing, albeit uneven across states.
4. **Standards and Compliance** becoming central: traceability, residue limits and certification started to shape competitiveness as much as traditional price factors.

4. Economic Assessment of Trade Liberalization

4.1. Conceptual Channels

Trade liberalization affects agriculture via **(i)** price transmission (domestic to world markets), **(ii)** resource reallocation (toward comparative advantage), **(iii)** scale and learning effects (through export orientation), and **(iv)** risk channels (global volatility, weather shocks, exchange rates). The net welfare effect depends on market structure, infrastructure, institutions (e.g., procurement, PDS), and social protection.

4.2. Market Access and Price Dynamics

1. **Tariffs and Applied Protection:** India's bound tariffs provide headroom; applied tariffs have been flexibly managed to balance consumer and producer interests. For staples, policy often leans toward stabilization via tariff changes, export controls and buffer stocks.

2. **Price Transmission:** Transmission is partial and heterogeneous—stronger for tradables with deep private value chains (e.g., cotton, spices) and weaker for MSP-procured staples (rice, wheat) where public procurement delinks farmgate prices from world prices.
3. **Volatility:** Liberalization can import volatility; however, public stockholding, variable tariffs and timely trade policy measures can smooth domestic prices—though at the cost of policy predictability for exporters.

4.3. Domestic Support and Incentive Structures

Input subsidies reduce production costs but skew incentives toward input-intensive crops and strains on natural resources (groundwater, soil health). MSP assures prices for cereals, shaping cropping patterns. From a WTO lens, the **classification** of support (Green vs Amber) and **measurement** (relative to reference prices) is critical to maintain policy space. Redirecting support toward **Green Box-compatible** investments (R&D, extension, climate-smart infrastructure, risk management) can sustain productivity without breaching disciplines.

4.4. Export Competition and Competitiveness

Export subsidies have largely phased down globally. India's competitiveness hinges increasingly on **non-price factors**: logistics, quality assurance, compliance with SPS rules, reputation, and branding (e.g., GI tags for basmati, Darjeeling tea, multiple spices). Efficient ports, reefer capacity, and predictable policies are now as decisive as relative costs.

4.5. SPS/TBT Compliance Costs and Upgrading

Compliance with residue limits, animal health protocols and traceability systems imposes fixed costs that can exclude smallholders. Yet the same standards, once met, unlock premium markets. Institutional innovations—cluster-based exports, common testing facilities, digital certificates and group certification—reduce per-farmer compliance costs and raise average quality.

4.6. TRIPS, Seeds and Innovation

Balanced plant variety protection frameworks can incentivize private R&D while safeguarding farmer rights to save, use, and exchange seeds. Public–private models and breeder–farmer partnerships are crucial to ensure innovation diffusion to smallholders and climate-resilient breeding pipelines.

4.7. Commodity Snapshots

- **Basmati Rice:** Gains from GI protection, quality upgrading, and branding; sensitivity to pesticide residue norms and destination-market SPS enforcement.
- **Cotton:** Integration with global value chains; exposure to world price cycles; technology adoption (including hybrid seeds) improved yields but raised demands on extension and stewardship.
- **Spices and Plantation Crops:** Strong export performance driven by quality niches; standards compliance and traceability are binding constraints and opportunities.
- **Horticulture:** Rising exports (mango, grapes, pomegranate) reflect improvements in cold chain and pack-house infrastructure; rejection risks underscore the need for robust MRL (maximum residue level) compliance and farm-level record-keeping.
- **Marine Products:** Rapid growth aided by aquaculture expansion and processing capacity; biosecurity and sustainability standards increasingly shape market access.
- **Edible Oils:** High and persistent import dependence illustrates how domestic supply constraints, consumption growth, and relative prices interact under liberalization.

4.8. Distributional and Regional Impacts

Liberalization's benefits accrue where market connectivity, infrastructure, and producer organizations are strong (e.g., western and southern horticulture belts; cooperative dairy ecosystems). Regions with rainfed, risk-prone agriculture gain less without complementary public investment. **Gendered impacts** arise because women are concentrated in labor-intensive tasks and informal segments; standards compliance and formalization can both exclude (via fixed costs) and empower (via skills and certification) depending on policy design.

4.9. Environmental Externalities and Climate Risks

Input-intensive growth has degraded soils, depleted groundwater, and raised GHG emissions from rice–wheat systems. Trade interacts with climate through **carbon standards**, consumer preferences, and supply-chain requirements (e.g., deforestation-free sourcing). A climate-smart competitiveness strategy—low-emission rice, water-saving irrigation, regenerative practices—can turn compliance into a market edge.

5. Empirical Strategy Blueprint

1. **Trade and Price Indicators:**
2. **Productivity and Welfare:**
3. **Standards and Upgrading:**
4. **Policy Evaluation**

6. Policy Implications for India under the WTO Regime

6.1. Preserving Food Security within Multilateral Rules

- **Public Stockholding:** Maintain adequate buffer stocks for the Public Distribution System (PDS), while improving targeting and reducing storage losses. Advance transparency on procurement prices, volumes, and stock rotation to strengthen the case for compatibility with multilateral disciplines.
- **Calibrated Trade Management:** Use tariff bands and transparent, rules-based triggers for temporary export restrictions on staples, communicating timelines and review mechanisms to preserve exporter credibility.

6.2. Rebalancing Support toward Productivity and Resilience

- **Green Box Shift:** Reallocate marginal rupees from input subsidies toward R&D (especially climate-resilient varieties), irrigation efficiency (micro-irrigation, aquifer recharge), soil health, and digital extension.
- **Risk Management:** Scale up **index-based and area-yield insurance**, integrate weather data and remote sensing for faster payouts, and promote warehouse receipt finance to smooth post-harvest distress sales.
- **Sustainable Intensification:** Incentivize **direct-seeded rice**, alternate wetting and drying, precision nutrient management (4R principles), and crop diversification in over-exploited blocks.

6.3. Competing on Quality, Not Just Price

- **National Quality Infrastructure (NQI):** Expand accredited labs, reduce testing turnaround times, and digitize e-phyto and certificate-of-origin systems.
- **Cluster-Based Compliance:** Support pack-houses, vapor heat treatment, and common traceability platforms for export clusters; enable **group certification** to spread fixed costs.
- **GI and Branding:** Invest in GI governance (specifications, control bodies, marketing), linking to sustainable practices that resonate with global buyers.

6.4. Smallholder Integration and Inclusion

- **FPOs and Cooperatives:** Professionalize FPO management, create blended finance facilities for working capital, and link FPOs to assured offtake via e-commerce, institutional buyers, and exporters.
- **Gender-Responsive Design:** Tailor training, credit, and certification pathways for women-led groups; recognize unpaid work in value-chain planning.
- **Digital Public Goods:** Leverage open digital stacks (ID, payments, logistics, agristack) to cut transaction costs and create auditable records for standards compliance.

6.5. Logistics, Trade Facilitation, and Domestic Markets

- **Cold Chain and First-Mile:** Expand pre-cooling, reefer transport, and multimodal logistics; pilot temperature-controlled corridors for horticulture.
- **APMC and Direct Marketing:** Encourage transparent e-trading and assaying; promote negotiable warehouse receipts and dispute-resolution mechanisms to improve price realization.
- **Border Efficiency:** Streamline port processes, risk-based inspections, and single-window clearances to lower dwell times and logistics costs.

6.6. Negotiation Strategy and Rule-Making

- **Agriculture Negotiations:** Continue advocating for a permanent solution on public stockholding, reasonable de minimis calculations reflecting inflation and current reference prices, and S&D (Special & Differential) flexibilities.
- **Standards Diplomacy:** Shape international standards (Codex, OIE/IPPC) and mutual recognition of conformity assessment; deploy attachés/technical experts in key markets.
- **New Issues:** Track carbon-related border measures and sustainability due-diligence regimes; build measurement, reporting, and verification (MRV) capacity to pre-empt barriers.

7. Risks, Trade-offs, and Safeguards

- **Policy Uncertainty:** Frequent export restrictions on staples safeguard consumers but can erode exporter credibility, deter private investment, and invite partner retaliation. Rule-based, time-bound measures can balance these trade-offs.
- **Natural Resource Stress:** Subsidy-driven input use without pricing externalities leads to aquifer depletion and soil degradation. Aligning incentives (power pricing reforms with lifeline protection, metering, micro-irrigation) is essential.
- **Exclusion Risks:** Standards and formalization can marginalize smallholders without subsidized compliance, last-mile extension, and group-based certification.
- **Macro Shocks:** Exchange-rate swings and global demand cycles require hedging instruments and diversified export baskets.
- **Climate Volatility:** Weather shocks amplify price instability; **anticipatory safety nets** (scalable cash transfers, PDS flexibility, emergency import/export windows) should be pre-designed.

8. Implementation Pathway: Turning Policy into Practice

8.1. Five Strategic Pillars

1. **Productivity & Resilience:** Invest in climate-smart R&D, seed systems, soil health missions, and water-saving irrigation; strengthen Krishi Vigyan Kendras and digital extension for rapid diffusion.
2. **Quality Infrastructure:** Scale accredited labs, create regional centers of excellence for SPS, and deploy interoperable digital certificates (residues, organic, GI, fair trade).
3. **Inclusive Market Institutions:** Professionalize FPOs with CFO/CEO support, create pooled input procurement and output marketing platforms, and link to **warehouse receipt finance**.
4. **Logistics & Trade Facilitation:** Expand pack-houses, reefer fleet, and rail-linked perishable hubs; implement risk-based inspections and single-window customs to cut dwell time.
5. **Rules-Compatible Support:** Migrate marginal subsidy outlays toward Green Box investments; ring-fence MSP/PDS for food security with transparent accounting and stronger leakage controls.

8.2. Monitoring and Evaluation

- **KPI Dashboard:** export rejection rates, test-turnaround times, logistics dwell time, FPO price realization vs mandi benchmarks, adoption of climate-smart practices, and insurance payout latency.
- **Adaptive Policy Loops:** quarterly reviews with producer associations, exporters, state departments, and standards bodies to course-correct.

9. Conclusion and Recommendations

The WTO has neither unambiguously constrained nor unconditionally propelled Indian agriculture; rather, it has **reframed the playing field**. Where domestic capabilities—productivity, quality assurance, logistics, and institutions—were strong, liberalization amplified gains. Where structural bottlenecks persisted, openness exposed vulnerabilities, and policy had to work harder to cushion shocks. The path forward is not a binary choice between protection and liberalization. It is a **smart openness** strategy built on five principles:

1. **Protect People, Not Inefficiency:** Preserve food security and safety nets, but migrate support from distortionary inputs toward productivity and resilience—well within Green Box space.
2. **Compete on Trust:** Build a reputation for reliable deliveries and credible quality—labs, certifications, and traceability are strategic assets, not compliance burdens.
3. **Enable Smallholder Scale:** FPOs, cooperatives, and digital platforms allow many small farms to act like one large, standards-compliant supplier.
4. **De-risk the Value Chain:** Insurance, warehouse receipts, hedging tools, and predictable trade rules reduce volatility costs.
5. **Shape the Rules:** Be proactive in negotiations on public stockholding, standards recognition, and sustainability metrics to ensure that rules reflect developing-country realities.

References:

Ghosh, M. (2017). WTO, Trade Liberalization, and Indian Agriculture. *Indian Agriculture Under Multilateral and Regional Trade Agreement-Competitiveness and Food Security Concerns*, 19-43.

Deodhar, S. Y. (1999). WTO agreements and Indian agriculture: Retrospection and prospects.

Ratna, R. S., Sharma, S. K., & Dobhal, A. (2021). Indian agriculture under WTO and FTAs: An assessment. In *Indian Agriculture Under the Shadows of WTO and FTAs: Issues and Concerns* (pp. 3-25). Singapore: Springer Singapore.

Mahadevan, R. (2003). Productivity growth in Indian agriculture: the role of globalization and economic reform. *Asia Pacific Development Journal*, *10*(2), 57-72.

Anderson, K., Hoekman, B., & Strutt, A. (2001). Agriculture and the WTO: Next steps. *Review of International Economics*, *9*(2), 192-214.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

Zero Budget Natural Farming: A pathway to Sustainable Agriculture

Jyoti Khatkar[1], Dr Rameshwar Singh[2], Anil Kumar[3] and Parveen Kumar[4]

[1&4]PG scholar, Department of Soil Science, CCS Haryana Agricultural University, Hisar
[2]Assistant scientist, Department of Soil Science, CCS Haryana Agricultural University, Hisar
[3]Department of Agronomy, CCS Haryana Agricultural University, Hisar

Introduction

Zero Budget Natural Farming (ZBNF) is based on the principle that farming should rely on minimal external inputs, thereby reducing the financial burden on farmers while maintaining soil fertility and crop productivity. It is regarded as an agroecology-based diversified farming system that integrates crops, trees, and livestock with functional biodiversity to support ecological balance. In India, natural farming is officially promoted through the **Bharatiya Prakritik Krishi Paddhati** (BPKP) under the centrally sponsored **Paramparagat Krishi Vikas Yojana** (PKVY). This program encourages the use of traditional indigenous practices that minimize reliance on externally purchased inputs. The core of natural farming lies in on-farm biomass recycling, with an emphasis on mulching, the application of cow dung- and urine-based formulations, periodic soil aeration, and complete exclusion of synthetic chemical inputs. Natural farming contributes to increased agricultural production, water conservation, improved soil health, and enhanced farmland biodiversity. It is recognized as a cost-effective and eco-friendly approach, with potential to generate rural employment and promote sustainable rural development. This method also offers a viable solution to major agricultural challenges such as farmer indebtedness, environmental degradation, and food insecurity. Subhash Palekar, the pioneer of ZBNF, introduced and promoted these practices extensively in Karnataka during the 1990s. His work aimed to counter the harmful effects of chemical-intensive agriculture and water-heavy irrigation systems commonly associated with conventional farming.

Key components of Zero Budget Natural Farming

The four pillars—Jeevamrut, Bijamrut, Acchadana and Whapasa—form the scientific and philosophical foundation of natural farming as proposed by Subhash Palekar.

1. Jeevamrut – Microbial Culture for Soil Enrichment

Jeevamrut is a fermented bio-culture made from cow dung, cow urine, jaggery, pulse flour, and a small quantity of soil from the farm itself. This preparation serves as a rich source of beneficial microorganisms that enhance the biological activity of the soil. These microbes decompose organic matter, converting it into readily available forms of essential nutrients like nitrogen, phosphorus and potassium. Regular application of jeevamrut improves soil fertility, structure, aeration and water retention capacity, promoting healthier and more resilient plant growth.

2. Bijamrut – Natural Seed Treatment

Bijamrut is a natural anti-fungal and antibacterial solution used for seed treatment before sowing. It is prepared using cow dung, cow urine, neem leaves and other medicinal plant extracts. Seeds treated with bijamrut are protected from soil- and seed-borne pathogens, ensuring safe germination and vigorous early growth. This natural method replaces chemical seed treatments, reduces input costs and improves crop resistance against diseases during the critical early stages of development.

3. Acchadana – Mulching for Soil Protection

Acchadana involves covering the soil surface with organic materials such as dry leaves, crop residues, straw, or live green cover. This practice conserves moisture by reducing evaporation, suppresses weed growth, moderates soil temperature, and creates a favourable habitat for soil microbes. As the mulch decomposes, it adds organic matter to the soil, enriching it with nutrients and improving its physical structure. Mulching also helps prevent soil erosion and supports long-term ecological balance in farmlands.

4. Whapasa – Soil Moisture and Aeration Balance

whapasa is a principle introduced by Subhash Palekar that emphasizes maintaining a balanced ratio of moisture and air in the soil. Unlike conventional practices that often rely on excessive irrigation, whapasa promotes minimal watering to ensure that plant roots receive both water and oxygen. This enhances root health, improves nutrient uptake, and increases drought resistance. By advocating for precise and need-based irrigation—typically during cooler hours of the day—whapasa helps conserve water and reduces the risk of root diseases.

Principles of Zero Budget Natural Farming:

ZBNF is based on a set of scientific and ecological principles that align with natural processes

1. Elimination of Chemical Inputs

A central tenet of ZBNF is the complete avoidance of synthetic fertilizers and chemical pesticides. Subhash Palekar argues that these chemicals degrade soil health, harm microbial life, and contaminate water sources. Instead, ZBNF relies on natural inputs like jeevamrut and bijamrut, which are made using farm-based materials such as desi cow dung and urine, jaggery, and pulse flour. These inputs foster soil microbial activity, enhance nutrient cycling, and strengthen the plant's natural immunity.

2. Use of Desi Cow and Its Derivatives

The indigenous (desi) cow is pivotal to ZBNF. Its dung and urine are core components in the preparation of natural farming inputs. Palekar asserts that the by-products of one desi cow are enough to sustain up to 30 acres of farmland. Cow dung is rich in beneficial microbes, while cow urine acts as a potent bio-pesticide and soil tonic.

3. Soil Microbial Enrichment

Soil fertility in ZBNF is built upon enhancing microbial life. Microorganisms decompose organic matter, fix atmospheric nitrogen, and solubilize nutrients for plant uptake. Regular application of jeevamrut ensures a thriving microbial ecosystem, which in turn improves soil structure, aeration, and moisture retention—eliminating the need for chemical fertilizers.

4. Promotion of Biological Pest Management

Instead of synthetic pesticides, ZBNF uses plant-based bio-pesticides like agniastra, brahmastra and neemastra, made from ingredients such as neem leaves, garlic, green chilies, and cow urine. These natural formulations effectively manage pest populations while preserving beneficial insects, such as pollinators and soil organisms.

5. Crop Diversity and Mixed Cropping

ZBNF promotes diverse cropping systems over monocultures. Intercropping cereals, legumes, vegetables, and fruits improves nutrient cycling, reduces pest outbreaks and stabilizes farm income. Crop diversity enhances ecological balance and resilience against weather extremes or market fluctuations.

Benefits of Zero Budget Natural Farming

1. Cost Reduction and Debt-Free Farming

One of the most significant advantages of ZBNF is that it reduces the cost of cultivation to nearly zero, by eliminating the use of synthetic fertilizers, pesticides, and other expensive agrochemicals. Farmers use locally available materials like desi cow dung, cow urine, jaggery and crop residues to prepare inputs. This makes farming self-reliant and helps prevent farmers from falling into debt cycles caused by input loans.

2. Soil Health Improvement

ZBNF focuses on restoring and maintaining soil fertility through microbial enrichment. The use of natural bio-inputs like jeevamrut boosts the population of beneficial microbes that decompose organic matter and recycle nutrients. Practices like mulching and crop rotation improve soil structure, increase organic matter and enhance water retention capacity. Over time, soils become more porous, fertile and resilient.

3. Enhanced Crop Yield and Quality

With regular application of jeevamrut and bijamrut and improved soil biology, farmers often observe better plant health and productivity. Crops grown under ZBNF are typically free from chemical residues, making them nutrient-rich and healthier for consumption. Additionally, the risk of pest and disease outbreaks is reduced due to increased biodiversity and stronger plant immunity.

4. Water Conservation

ZBNF's whapasa principle—which emphasizes maintaining both air and moisture in the soil—leads to drastically reduced water requirements. Through mulching and minimal irrigation techniques, farmers can conserve water by up to 50-60%. This is particularly beneficial in drought-prone or rainfed regions where water scarcity is a major constraint.

5. Biodiversity and Ecological Balance

ZBNF encourages diverse cropping systems, intercropping, agroforestry, and the use of natural pest control methods. This promotes ecological balance, supports pollinators and natural predators and restores native biodiversity. It also reduces dependence on monocultures, which are more vulnerable to pests, diseases, and climate fluctuations.

6. Climate Resilience

By improving soil organic matter, enhancing water retention and promoting crop diversity, ZBNF increases resilience against climate stressors such as droughts, flood and temperature extremes. Healthy soils sequester more carbon and buffer against erosion, making ZBNF a climate-smart agriculture practice.

7. Improved Farmer Livelihood and Profitability

Due to lower input costs and stable yields, farmers practicing ZBNF often experience higher net incomes and improved livelihood security. The approach is particularly helpful for smallholders who cannot afford expensive inputs and often face financial instability under conventional agriculture.

8. Health and Food Safety

Since ZBNF avoids chemical fertilizers and pesticides, the produce is free from toxic residues, making it safer for consumers. It also reduces exposure of farmers and farm workers to hazardous agrochemicals, improving human and environmental health.

9. Social and Cultural Revival

ZBNF encourages the use of traditional knowledge, indigenous cattle breeds and local resources, helping revive cultural and community-based farming practices. It builds a sense of ownership and pride among farmers, strengthens community cooperation and promotes agricultural self-sufficiency.

Challenges of Zero Budget Natural Farming (ZBNF)

Reduced Yields During Transition

When shifting from conventional to natural farming, farmers often notice a temporary drop in crop productivity, which can affect income and food security.

Scarcity of Indigenous Cattle

ZBNF depends heavily on dung and urine from local (desi) cow breeds. However, not all farmers have access to these animals, limiting the practicality of the method.

Increased Labor Demands

Natural farming practices like preparing organic mixtures, mulching and manual weed control require more physical effort compared to mechanized or chemical-based farming.

Limited Scientific Evidence

There is a lack of extensive scientific studies and field data to validate ZBNF's effectiveness across different regions and crops, making experts cautious about recommending it widely.

Weak Market Support

Natural produce often lacks formal certification, making it difficult for farmers to access premium markets or earn better prices for their goods.

Insufficient Awareness and Training

A large number of farmers are either unaware of ZBNF or do not have adequate training to implement its techniques effectively.

Economic Uncertainty During Shift

The transition to ZBNF can involve financial risk, particularly for small-scale farmers who depend heavily on consistent yields for their livelihood.

Role of ZBNF's in Sustainable Agriculture

Sustainable agriculture seeks to address the rising global demand for food while safeguarding environmental integrity, improving soil health, protecting biodiversity, and supporting farmers' livelihoods. With growing concerns over climate change, soil depletion, and the overuse of chemical inputs, there is a pressing need for environmentally friendly and economically feasible farming systems. Zero Budget Natural Farming (ZBNF), introduced by Indian agronomist Subhash Palekar, offers a promising solution to these pressing issues. It promotes cultivation without chemical fertilizers or pesticides and reduces farming costs by utilizing natural resources available on the farm. ZBNF emphasizes regenerative techniques that rebuild soil fertility and reduce water dependency, making it highly relevant to the future of sustainable agriculture. By enhancing soil microbial life and organic content, it not only increases plant resilience but also aids in carbon storage—an important factor in combating climate change. With the right support, research, and farmer participation, ZBNF has the potential to become a foundational model for sustainable farming. It can uplift smallholder farmers, preserve natural ecosystems, and strengthen global food security—provided the challenges are addressed through collective action and continued innovation.

Conclusion

Zero Budget Natural Farming (ZBNF) presents a sustainable, environmentally friendly, and cost-effective alternative to modern chemical-based agriculture. It eliminates the use of synthetic fertilizers and pesticides, instead utilizing natural, farm-based inputs to rejuvenate soil fertility, protect biodiversity, and lower cultivation costs. This method encourages farmer self-sufficiency, particularly benefiting small and marginal farmers by reducing their financial burden and increasing long-term productivity. In the face of growing challenges such as climate change, declining soil quality, and rising food insecurity, ZBNF emerges as a promising approach to regenerative agriculture. Its widespread adoption, supported by research, policy, and farmer training, could significantly contribute to a more resilient and sustainable future for agriculture.

INNOVATIVE AGRICULTURE
www.innovativeagriculture.in
ISSN : 3048 - 989X

From Whole Grain to Polished Grain: A Critical Reassessment of the Nutritional Quality, Glycemic Properties, and Public Health Implications of Millets

Meena, A.,[1] Ankita, T.[2] and Tannu, R.[3]

[1]Ph.D. scholar, Plant Pathology, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. Pin 263145.

[2]M.Sc. scholar, Plant Pathology, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. Pin 263145.

[3]Ph.D. scholar, Plant Pathology, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. Pin 263145.

Abstract

Millets are increasingly recognized as nutrient-rich cereals with great potential to combat undernutrition, micronutrient deficiencies, and diet-related non-communicable diseases. They offer well-balanced macronutrients, 65–75% carbohydrates, 8–15% protein, and higher mineral levels—such as calcium, iron, magnesium, and phosphorus—than rice and wheat. Rich in dietary fiber and bioactive compounds, millets provide functional benefits for metabolic health and cardiovascular protection. However, processing techniques like de-branning and polishing significantly diminish proteins, lipids, minerals, and phytochemicals, while increasing rapidly digestible carbohydrates by 8–11%. Studies show that even unpolished varieties like foxtail and little millet have glycemic indices (GI) similar to polished rice (GI ≈ 88–89), questioning their classification as “low-GI” foods. Market research indicates that over 90% of retail millet brands sell polished grains, often falsely marketed as health foods, leading to consumer misconceptions. Although traditional methods such as fermentation and germination improve bioavailability and micronutrient retention, modern refining reduces these nutritional benefits. For millets to play a meaningful role in sustainable diets and public health, clear labeling, consumer awareness, and promotion of whole or minimally processed grains are crucial.

Keywords

Millets; Nutritional quality; Glycemic index; Processing methods; Dietary fiber; Micronutrient deficiencies; Consumer perception; Public health

Introduction

Millets, belonging to the Poaceae family, encompass a variety of small-seeded cereals such as foxtail, little millet, kodo, barnyard, proso, pearl millet, finger millet, and sorghum. Once considered “poor man’s food,” they are now recognized as “nutri-cereals” due to their high nutrient content and resilience against harsh environmental conditions. Despite India producing nearly 41% of the world's millet, the country still faces significant child malnutrition and rising rates of non-communicable diseases like type 2 diabetes and obesity. This paradox highlights the critical need to diversify diets, which are often limited to refined rice and wheat, by including more nutrient-dense whole grains.

Nutritional Potential of Millets

1. Macronutrients and Micronutrients in Millets

Millets are nutrient-dense cereals with 320–370 kcal per 100 g, comparable to rice and wheat but distinguished by a more balanced nutrient profile. They encompass carbohydrates, proteins, fats, fiber, vitamins, and minerals that support counteracting undernutrition and prevent non-communicable diseases.

2. Carbohydrates and Starch Quality

Carbohydrates, predominantly slowly digestible and resistant starches, constitute 65–75% of millets. These release glucose gradually, thereby enhancing satiety and glycemic regulation. Finger and foxtail millets exhibit high amylose content, contributing to a lower glycemic response. Polishing increases carbohydrate content by 8–11%, elevating the glycemic load.

3. Proteins and Amino Acid Profile

The protein content in millets ranges from 8 to 15 g per 100 g. Foxtail and proso millets exhibit higher protein levels. However, low lysine levels, methionine and cysteine are relatively elevated compared to rice and wheat. Proso millet demonstrates a 51% higher essential amino acid index than wheat, underscoring superior protein quality.

4. Lipids and Fatty Acid Composition

Millets contain 1–6% lipids, primarily comprising beneficial fatty acids. Pearl millet includes omega-3 fatty acids, linoleic acid, and alpha-linolenic acid, which are advantageous for cardiovascular health. Lipids tend to concentrate in the bran; therefore, de-branning reduces their content.

5. Dietary Fiber and Functional Carbohydrates

Whole millet provides dietary fiber ranging from 8 to 14 g per 100 g, markedly exceeding polished rice at 0.5 g. Dietary fiber contributes to satiety, glycemic regulation, and gastrointestinal health. The process of de-branning reduces fiber content by up to 54% in foxtail millet, diminishing these health benefits.

6. Minerals: Calcium, Iron, Magnesium, and Phosphorus

Finger millet is notably rich in calcium (364 mg per 100 g), supporting bone health. Pearl millet, proso millet, and little millet contain higher iron levels than rice, helping to fight anemia. Barnyard and foxtail millet offer significant magnesium and phosphorus, essential for energy metabolism and neuromuscular function. Zinc and selenium are vital for immune support and decrease with polishing.

7. Vitamins and Phytochemicals

Millets provide B-complex vitamins, vitamin E, and bioactive phytochemicals like polyphenols, flavonoids, and phytosterols, which act as antioxidants. Proso millet contains chlorogenic and ferulic acids; finger millet is high in tannins and polyphenols.

Glycemic Properties of Millets

Millets are promoted as low-glycemic index foods due to their fiber, resistant starch, and phytochemicals, which slow starch digestion and help moderate blood sugar spikes.

a. Role of Whole-Grain Structure

The bran and germ layers block enzymatic digestion, and resistant starch and non-starch polysaccharides prolong glucose release, leading to longer satiety and better metabolic health.

b. Effect of Processing on Glycemic Response

Removing the bran (debranning) decreases fiber and minerals, raising accessible carbohydrates by 8–11%. Polished grains cook faster and resemble refined rice, but with fewer nutrients.

c. Evidence from Glycemic Index Studies

Research shows that unpolished foxtail and little millets have a glycemic index around 88.6, similar to rice at about 89. So, not all millets naturally have a low glycemic index.

d. Implications for Diabetes and Metabolic Health

While millets improve dietary variety and micronutrient intake, relying solely on them for low-glycemic benefits can be misleading. Their true value lies in their overall nutritional contribution and sustainability.

Experimental Evidence: Effects of De-branning

1. Loss of Proteins, Fats, and Dietary Fiber

De-branning removes nutrient-rich bran and germ, causing a decrease of up to 54% in proteins, fats, and dietary fiber in foxtail millet. This reduction lessens satiety and glycemic benefits.

2. Reduction in Mineral Density

Magnesium, zinc, calcium, and phosphorus levels drop by 40–50%, reducing their ability to address deficiencies.

3. Depletion of Phytochemicals

Significant declines in bioactive compounds such as polyphenols and flavonoids weaken antioxidant and anti-inflammatory effects.

4. Increase in Available Carbohydrates

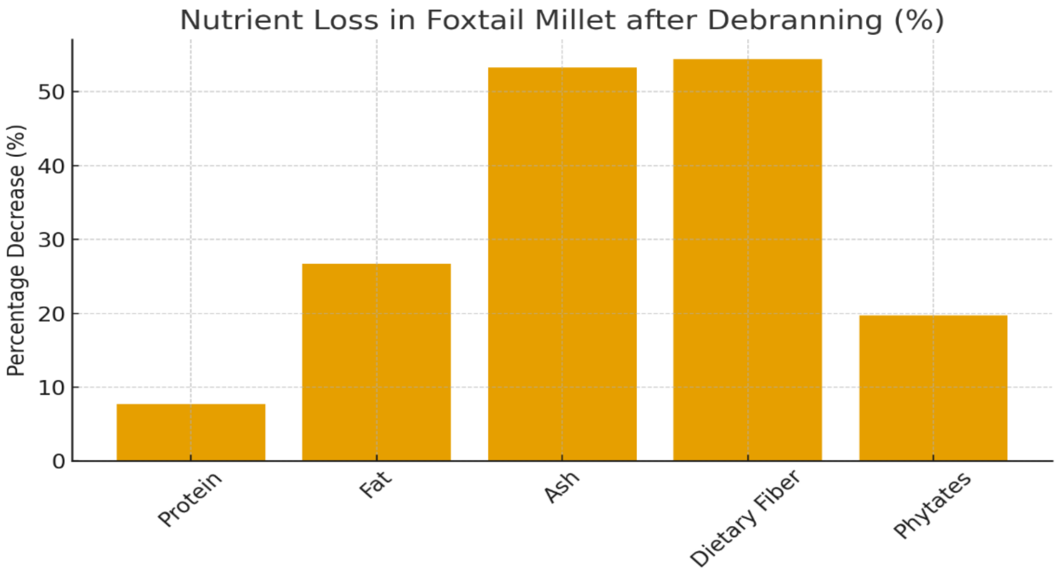
Carbohydrate content rises by 8–11%, raising the glycemic load to levels similar to refined rice.

5. Microstructural Damage

Scanning Electron Microscopy (SEM) shows loss of protective grain layers, which decreases structural integrity, increases water absorption, and shortens cooking time.

6. Broader Nutritional Consequences

Although debranning improves market appeal, it also reduces nutritional quality and glycemic stability, which can undermine health benefits.



Cooking Behavior and Nutrient Retention:

Debraned grains cook faster because of exposed starchy endosperm, but this also increases nutrient leaching into the cooking water. Essential minerals like magnesium and zinc, already reduced, are further lost in this process. While dehusked grains retain more nutrients, they require longer cooking times.

Traditional versus Modern Processing of Millets:

Traditional fermentation, germination, malting, and roasting methods enhance nutrient bioavailability.

- Fermentation reduces phytate levels, improving mineral absorption and increasing B vitamins.
- Germination activates enzymes that improve protein digestibility, amino acid balance, and vitamin C content.
- Malting raises soluble sugars and antioxidants, while roasting enhances flavor but may decrease heat-sensitive vitamins.
- Contemporary methods like industrial milling, debranning, and polishing focus on convenience but cause nutrient loss.
- De-branning can cut fibre and mineral content by up to 50%.
- Polishing increases carbohydrate levels by 8–11% but decreases proteins and phytochemicals, raising the glycemic index.
- Loss of phytochemicals reduces antioxidant capacity and health benefits.

Balancing Tradition and Modernity:

Traditional processing boosts nutrient levels, whereas modern practices often cause nutrient depletion. Combining gentle dehulling with fermentation or germination can improve taste and retain nutrients.

Market Realities and Perceptions:

About 90% of market-available millets are polished, making them look like rice to meet consumer preferences, but at the expense of nutrients.

Processing Trends:
Polished millets are popular because they look appealing and cook quickly, although nutritionally they are similar to refined rice.

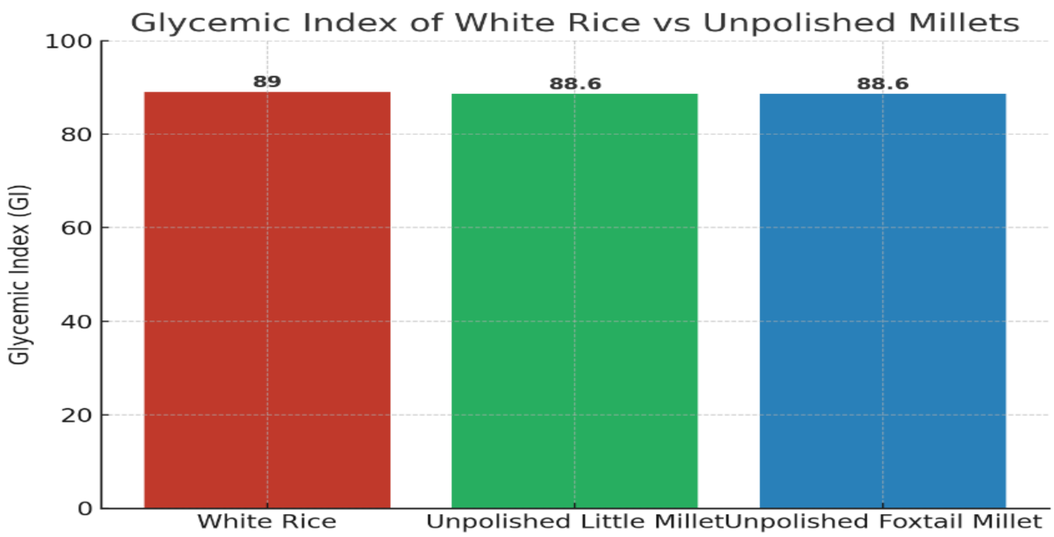
Health Claims and Consumer Awareness:
Labels often use misleading terms like “diabetic-friendly,” even though nutrients are lost—fiber decreases by up to 50%, and glycemic index values mirror rice. Many consumers are unaware of polishing effects, often equating whiteness and softness with quality.

Public Health and Policy Implications:
The dominance of polished millets may hinder health benefits such as better iron absorption and blood sugar control. Clear, accurate messaging is crucial. Policy recommendations include transparent labeling, regulation against false claims, public education on whole grains, and incentives for marketing whole millets.

Glycemic Index Insights:
Contrary to common belief, studies show that unpolished foxtail and little millet have high glycemic indices similar to rice—starch content, partial polishing, cooking methods, and fiber influence glycemic response.

Public Health Strategies:
Simply replacing rice with millet doesn't guarantee better glycemic outcomes. Labels should accurately report GI, and education should cover species differences and processing impacts. Regulations should differentiate between whole and polished grains.

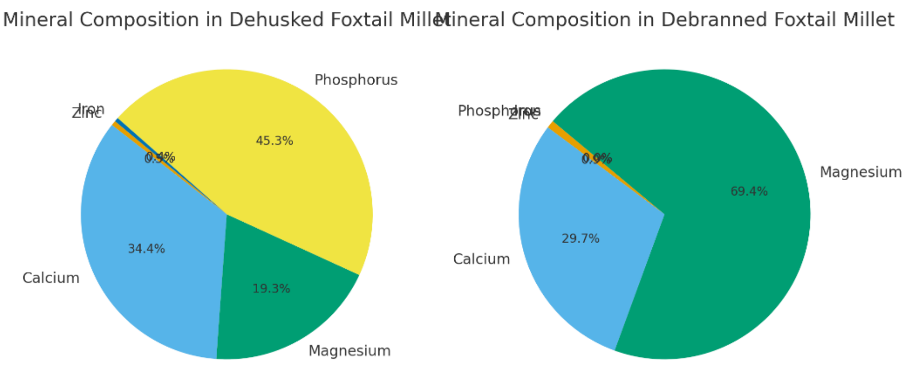
Millet Advocacy Reconsidered:
While valued for micronutrients and sustainability, millets aren’t naturally low-GI foods. Promotion should emphasize whole grains, diverse preparation, and honest consumer information.



Public Health Implications of Millet Consumption
Whole millets are rich in calcium, iron, magnesium, and phosphorus. Finger millet is exceptionally high in calcium. They aid in combating anemia and hidden hunger. Fiber and phytochemicals support cholesterol reduction, satiety, and antioxidant protection. Yet GI studies show values close to rice.

Sustainability
Millets need one-third the water of rice, emit fewer greenhouse gases, and thrive in poor soils, making them climate-resilient crops.

Risks of Polished Varieties
Nutrient losses reach 50%, GI rises, and misleading claims persist. Over 90% of market millets are polished.



Policy and Strategic Recommendations

The following measures are recommended to maintain the nutritional integrity of millet grains.

1. Establish clear labeling regulations to differentiate between polished and unpolished grains.
2. Enhance consumer awareness through targeted campaigns. Incorporate unpolished millets into public distribution systems and school meal programs.
3. Promote innovations in the food industry that use minimally processed grains.
4. Investigate processing techniques that extend shelf life while preserving nutritional value.

Conclusion

Millets are ancient grains that remain relevant in modern diets. Their nutritional benefits are most pronounced when consumed in whole grain form; however, excessive polishing can reduce their nutritional content to levels similar to white rice. Policies, research initiatives, and consumer preferences must work together to promote and preserve the nutritional integrity of millets to combat malnutrition and health issues related to lifestyle choices effectively.

References

Shobana, S., Mohanraj, K., Malleshi, N. G., Rao, B. D., Anjana, R. M. and Mohan, V. (2024). Impact of debranning on the nutritional, cooking, microstructural characteristics of five Indian small millets. *Discover Food*, *4*(1), 136.

Gowda, N. N., Siliveru, K., Prasad, P. V., Bhatt, Y., Netravati, B. P. and Gurikar, C. (2022). Modern processing of Indian millets: a perspective on changes in nutritional properties. *Foods*, *11*(4), 499.

Malavika, M., Shobana, S., Vijayalakshmi, P., Ganeshjeevan, R., Gayathri, R., Kavitha, V., Gayathri, N., Savitha, R., Unnikrishnan, R., Anjana, R. M. and Malleshi, N. G. (2020). Assessment of quality of minor millets available in the south Indian market & glycaemic index of cooked unpolished little & foxtail millet. *Indian Journal of Medical Research*, *152*(4), 401-409.