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On-Farm Detection of Chronic Endometritis: Biochemical and Cytological Approaches

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Introduction

Chronic endometritis in dairy cattle is an underdiagnosed but economically significant reproductive disorder. Characterized by persistent inflammation of the uterine lining (endometrium), it often leads to reduced conception rates, prolonged calving intervals, and repeat breeding problems. Traditionally addressed with antibiotics or hormonal therapy, recent advances are opening new avenues in biochemical intervention, targeting the molecular and cellular mechanisms underlying this condition for more precise and sustainable treatment outcomes.

Understanding the biochemical roots of endometritis

Chronic endometritis is primarily caused by persistent bacterial infections, most commonly *Escherichia coli*, *Trueperella pyogenes*, and *Fusobacterium necrophorum*. These pathogens disrupt the normal uterine environment, leading to excessive production of inflammatory mediators such as prostaglandins (PGs), cytokines (like IL-6 and TNF-α), and reactive oxygen species (ROS). This disrupts the endometrial repair process and compromises the implantation of embryos. The condition is also associated with hormonal imbalances especially suboptimal levels of progesterone, which are essential for preparing the uterus for pregnancy and modulating the immune response.

What Causes Endometritis in Dairy Cattle?

Endometritis is an infection or inflammation of the uterus (womb) in cows. It is one of the most common reasons why cows don't conceive even after repeated inseminations. Understanding the causes can help farmers prevent it and take early action.

1. Bacterial infections

After calving (giving birth), the cow's uterus is open and exposed. Bacteria from the environment can easily enter and cause infection. If the cow's body doesn't clear these bacteria properly, it leads to chronic endometritis.

Common bacteria involved:

- *E. coli* – comes from dung or dirty surroundings
- *Trueperella pyogenes* – causes pus and foul-smelling discharge
- *Fusobacterium* – makes the infection worse

2. Retained placenta (Afterbirth)

If the placenta does not come out within 12 hours after calving, it starts rotting and attracts bacteria. This is a major cause of uterine infection.

3. Poor cleanliness during or after calving

- Dirty calving pens
- Unhygienic handling during assisted deliveries or artificial insemination
- Flies and manure in calving areas

4. Difficult or assisted Calving

- If the cow had a hard delivery or required pulling of the calf
- Use of unclean hands or tools during delivery
- Injury or tearing of the uterus during delivery

5. Weak immunity or nutritional deficiency

- Cows with low energy, low calcium or lacking in selenium and Vitamin E can't fight infections well.
- They also heal slowly after calving.

6. Repeat breeding and hormonal imbalance

- If a cow doesn't come into proper heat or has low progesterone, the uterus doesn't heal.
- Repeated insemination in such cows can worsen the infection.

7. Other risk factors

- Overcrowding
- Heat stress
- Poor drainage in sheds
- Overuse of antibiotics without proper diagnosis

When to suspect endometritis

- Cow had a difficult or assisted calving
- Placenta was retained for more than 12 hours
- Cow has abnormal vaginal discharge after calving
- Cow is not getting pregnant despite showing heat
- Cow is otherwise healthy but not conceiving

Symptoms

- Repeat Breeding
- Delayed or Irregular Heat
- Vaginal Discharge: White, yellowish, or brownish Mucus mixed with pus
- Sometimes foul-smelling, often noticed after the cow lies down or gets up
- Prolonged Uterine Involution
- Low Milk Yield
- Mild or No Fever
- Retained Placenta or History of Difficult Calving

Biochemical changes:

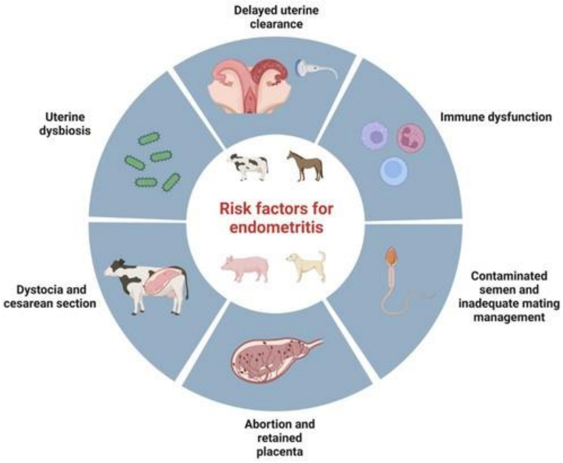
1. **Persistent inflammatory cytokines**
   - ↑ **Tumor Necrosis Factor-alpha (TNF-α)**
   - ↑ **Interleukins** such as IL-1β, IL-6, and IL-8

   These cytokines sustain inflammation, damage endometrial cells, and impair implantation.
2. **Oxidative stress markers**
   - ↑ **Reactive Oxygen Species (ROS)**
   - ↓ **Total Antioxidant Capacity (TAC)**
   - ↑ **Malondialdehyde (MDA)** – a byproduct of lipid peroxidation
3. **Altered prostaglandin profile**
   - ↑ **Prostaglandin F2-alpha (PGF2α)** causes luteolysis, affecting progesterone production and disrupting the estrous cycle.
4. **Endocrine imbalance**
   - ↓ **Progesterone (P4)** – essential for uterine quiescence and embryo survival
   - Erratic **estradiol (E2)** levels – affects immune modulation in the uterus
5. **Elevated acute phase proteins**
   - ↑ **Haptoglobin**
   - ↑ **Serum Amyloid A (SAA)** – systemic indicators of inflammation

Diagnosis: Biochemical and molecular techniques

1. **Uterine cytokine profiling**
   - ELISA-based quantification of TNF-α, IL-6 and IL-1β in uterine washings or endometrial tissue
2. **Oxidative stress analysis**
   - Spectrophotometric assays to measure ROS, MDA, GSH, SOD, and catalase activity
3. **Hormone profiling**
   - Progesterone and estradiol levels in serum or milk using RIA/ELISA
4. **Acute phase protein assays**
   - Colorimetric or immunoturbidimetric methods to quantify haptoglobin and SAA
5. **PCR and qPCR for pathogen detection**
   - Molecular detection of bacterial DNA (e.g., *E. coli*, *T. pyogenes*) from uterine swabs
6. **Endometrial biopsy with histochemistry**
   - Evaluates glandular structure and inflammatory cell infiltration; often combined with immunohistochemical staining for cytokines.

Common risk factors associated with endometritis in domestic animals.



Field-Level Tests for Detection of Chronic Endometritis in Dairy Cattle

Chronic endometritis often goes undetected due to subclinical presentation. Early detection is crucial to prevent reproductive inefficiency. While field-level tests offer rapid, cost-effective and on-the-spot screening options for veterinarians and dairy farmers

Recommended Combination for Field Screening

For herd-level screening, a combination of WST + cytology or WST + Metricheck provides a reliable and field-adaptable diagnostic approach.

Biochemical treatment options

1. **Antioxidant Therapy**
   - Vitamin E and Selenium: Enhance antioxidant defenses
   - N-Acetylcysteine (NAC): Acts as a precursor for glutathione synthesis
   - Plant polyphenols: Quercetin, curcumin, and resveratrol reduce ROS and inhibit NF-κB pathway
2. **Cytokine Modulation**
   - Lactoferrin: Downregulates IL-1 and TNF-α expression
   - Recombinant IL-10 or TGF-β: Anti-inflammatory cytokines to restore uterine homeostasis
3. **Prostaglandin Inhibitors**
   - NSAIDs (e.g., flunixin meglumine): Reduce PGF2α and help in luteal maintenance
   - Targeting COX-2 enzyme can reduce uterine inflammation
4. **Hormonal Therapy (Biochemically Timed)**
   - Progesterone supplementation via CIDR devices to support luteal function
   - GnRH analogs to induce ovulation and synchronize estrus
   - PGF2α (in mild inflammation) to induce uterine clearance
5. **Exosome-based Biotherapeutics (emerging)**
   - Exosomes from mesenchymal stem cells (MSCs) or granulosa cells carry anti-inflammatory miRNAs and peptides, reduce oxidative stress, and promote regeneration
6. **Nutritional Immunomodulation**
   - Supplementation with zinc, omega-3 fatty acids and amino acids like arginine improves the uterine immune environment

Biochemical Interventions: A Paradigm Shift

Recent research focuses on modulating these biochemical pathways instead of relying solely on antibiotics. The key strategies include:

1. Antioxidant therapy: Vitamin E, selenium, N-acetyl cysteine (NAC), or plant-derived polyphenols helps neutralize ROS, improving uterine tissue repair and reducing inflammation.

2. Immunomodulators: β-glucans, bovine lactoferrin, or recombinant cytokines (e.g., IL-10) are used to modulate the local immune response. By balancing pro- and anti-inflammatory signals, these agents promote endometrial healing and help the cow return to normal fertility faster.

3. Prostaglandin modulators: Non-steroidal anti-inflammatory drugs (NSAIDs) or specific inhibitors of prostaglandin synthesis (such as flunixin meglumine) can reduce uterine inflammation and improve conception rates when timed appropriately post-calving.

Table 1. Field-Level Tests for Detection of Chronic Endometritis in Dairy Cattle

Test Name	Purpose	Materials Needed	Procedure (Simple Steps)	Result Interpretation	Time Required
White Side Test (WST)	Detect inflammation (pus cells in mucus)	Cervical mucus, 5% NaOH, test tube, heat source	Mix 1 mL mucus with 1 mL 5% NaOH → Heat for 1–2 mins → Observe color	Yellow = Normal; Turbid/Brown = Infection	5 minutes
Metri check Test	Check mucus quality/discharge	Metri check device or clean gloved hand	Insert device in the vagina and collect mucus → Examine for color, odor, consistency	Clear = Normal; Pus/discolored/foul = Suspected infection	2 minutes
Vaginal pH Test	Detect abnormal pH due to infection	pH paper or portable pH meter	Collect mucus sample → Dip pH paper or probe → Read pH	Normal: 6.8–7.0; Infected: >7.5	1 minute
Uterine Cytology (Smear Test)	Count neutrophils (PMNs) in uterus	Cytobrush or AI sheath, glass slide, stain, microscope	Collect uterine sample → Smear on slide → Stain (Giemsa/Diff-Quick) → Observe under microscope	>5% PMNs = Endometritis	15–20 minutes
Rectal Palpation	Assess uterine size and tone	Arm-length gloves, lubricant	Insert gloved hand per rectum → Feel uterus size, symmetry, and consistency	Enlarged/flabby uterus = Delayed involution/infection	2–3 minutes
Discharge Scoring (Visual)	Grade discharges in post-calving cows	Clean gloved hand or visual exam	Pull vulva, observe discharge	Score 0 (clear) to 3 (purulent/foul); Score 2–3 = Infection	Instant

4. Hormonal synchronization and biochemical markers: Ovsynch, combined with biochemical monitoring of progesterone and estradiol levels, can be used to regulate estrous cycles and enhance uterine recovery. Additionally, measuring biomarkers such as acute-phase proteins (haptoglobin, serum amyloid A) helps in diagnosing subclinical infections and evaluating the response to therapy.

Control Measures for Chronic Endometritis in Dairy Cattle

Preventing chronic endometritis begins with maintaining good hygiene during and after calving. Clean and dry calving pens, proper sanitation of hands and instruments during assisted deliveries or artificial insemination and timely removal of placenta are critical. Cows that experience difficult calving, retained placenta, or stillbirth should be closely monitored for signs of uterine infection. Providing balanced nutrition, especially after calving, with adequate levels of energy, protein, minerals (like selenium and zinc), and vitamins (like A and E) boosts the cow's immunity and supports uterine healing. Regular reproductive health checks using simple field tests like the White Side Test or Metricheck device can help in early detection. If symptoms are noticed, timely veterinary intervention with appropriate anti-inflammatory, hormonal, or supportive therapy is essential. Avoid overuse of antibiotics without proper diagnosis and always follow the vet's advice. Good record-keeping, maintaining proper breeding intervals, and avoiding stress through proper housing and management are also important long-term strategies to control endometritis and improve fertility in dairy herds.

Conclusion

Chronic endometritis is a complex, multifactorial disease that no longer needs to rely solely on conventional therapies. Biochemical interventions offer a smart, targeted approach to understanding and resolving the underlying pathophysiology. With a growing body of research supporting these methods, the future of reproductive health in dairy cattle looks promising, healthier cows, improved fertility, and greater productivity.

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Beyond the Nets: Exploring the Sustainable Alternative Livelihood Opportunities for Coastal Fisherfolks

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Introduction

The Indian Ocean has been the source of livelihood and life for millions, particularly coastal fisherfolks. Seafood consumption is increasing all over the world, putting more pressure on marine resources. To address this increasing demand without over-exploiting marine resources, it is crucial to embrace sustainable management of fisheries. This method not only saves the environment but also assists other efforts at an international level to achieve Sustainable Development Goals like poverty eradication (SDG 1), zero hunger (SDG 2), community wellness (SDG 3), gender equality (SDG 5), clean water and sanitation (SDG 6), economic growth (SDG 8), sustainable consumption and production (SDG 12), climate change (SDG 13) and life below water (SDG 14) will fulfil present demand without compromising the future resources (Ratheesh et al., 2023).

Although, the fisheries sector made notable contribution of 5.23 percent to India's GDP in 2019, the socio-economic position of fisherfolk still remain underdeveloped. Most fisherfolk in India are poor with limited access to nutrition, education and healthcare. Rahaman et al., (2021) observed that these vulnerable communities often contend with overcrowded households, irregular seasonal works and weak social infrastructure. Health risks often arise from occupational exposures and poor sanitation.

Similar economic struggles are encountered in Cirebon coastal region of Indonesia, A study by Sukono et al., (2021) found that income was influenced by fishing technology, environmental degradation, capital and climate variability. Seasonal bans often lead to loss income, food insecurity and noncompliance. As there is lack of options during these fishing ban period, many fishers are forced to borrow money or rely on informal sectors pushing them to cycles of debt (Islam et al., 2021; Tripathy et al., 2017).

In addition, similar issues prevail in Kuala Dungan region of Malaysia, where, Ahmed et al., (2021) noted that the seasonal nature of fishing coupled with limited education and few supplementary income sources, keeps families trapped in poverty. These recurring patterns across coastal communities indicate a pressing need for structured and sustainable alternative livelihood programs. Whereas, In Ghana, Studies shows that only four to 20 percent of fishers engage in alternative income generating activities such as crop farming, livestock rearing, teaching and petty trading to supplement their low and unstable fishing income. Despite the cultural attachment to fishing, they expressed willingness to shift to alternative occupations (over 70%), this study emphasizes the livelihood diversification as not only a part of poverty reduction but also for easing fishing pressure a sustainable fishing management (Asiedu & Nunoo, 2013).

Need for Economic and Livelihood Diversification

Globally, marine fishing communities face increasing livelihood stress due to declining marine stocks, climate impacts and economic uncertainty. Studies from Zanzibar to the U.S. West Coast reveal growing dependency on supplementary and alternative job opportunities like farming or construction to buffer seasonal or income shocks (Ali et al., 2023;Hamad et al., 2023; Trekle et al., 2023). However, such transition is difficult in regions with limited job diversity and deep cultural ties to fishing.

In India, this is accurately evident in coastal states like Kerala and Tamil Nadu, where more than 60% of fishers depend solely on fishing. There is now an urgent need to identify and implement sustainable alternative or supplemental livelihoods that are ecologically viable, economically rewarding and socially acceptable (Salim et al., 2019).

Alternative Livelihood Opportunities among Coastal Fisherfolks

1. Deep Sea Fishing

India's expansive Exclusive Economic Zone (EEZ) is still untapped, especially for marine fauna such as yellowfin tuna, skipjack and squid. Diverting fishing efforts from saturated coastal areas to deep-sea areas can be a turning point. With proper training, sophisticated boats and official patronage, deep-sea fishing can lift incomes while relaxing pressure on coastal fishing (CMFRI Annual Report, 2017).

2. Seaweed Farming

Seaweed cultivation is becoming a sustainable and equitable source of livelihood for coastal peoples, particularly in low and middle income countries (LMICs).

In contrast with intensive aquaculture systems such as shrimp farming, seaweed farming needs less input, has a low environmental impact and can assist climate resilience by sequestering excess nutrients and mitigating coastal. Despite these benefits, its embracement across low and middle income countries is uneven because of several impediments. Seaweed is missing from the food and agriculture policies of most of Africa, South Asia and Latin America. In countries other than Indonesia or the Philippines, few LMICs have invested heavily in developing value chains for seaweed (Webb et al., 2023).

India's coast accommodates more than 1,000 species of seaweeds. It is emerging as a sustainable solution to address nutritional deficiencies and to improve coastal livelihoods. Of the 844 seaweed species identified, around 60 are commercially valuable, prompting government support through Pradhan Mantri Matsya Sampada Yojana (PMMSY), which allocated ₹640 crore from 2020 to 2025 for seaweed cultivation (Ministry of Fisheries, Animal Husbandry & Dairying., 2025).

Seaweed cultivation sustains eco-restoration, provides employment and provides raw materials for food, pharmaceutical and cosmetics industries. But concerns such as climatic volatility and post-harvest infrastructure are issues that require concentrated policy attention (CMFRI, 2017).

Seaweed farming is a new and low-profile livelihood option, especially for women's self-help groups (SHGs) in Tamil Nadu. Cultivation of *Kappaphycus alvarezii* with basic bamboo rafts has empowered fisherwomen in Ramanathapuram and Kanyakumari districts of Tamil Nadu, India, earning ₹3,000 to ₹10,000 per month (Rajasree and Gayathri, 2014).

With brief cycles of cultivation (around six weeks) and small returns per crop, it is already changing lives in places such as Tamil Nadu, Zanzibar and Madagascar (Rajasree & Gayathri, 2014). Still, challenges such as disease outbreaks (e.g., ice-ice syndrome), salinity changes, lack of quality seedstock and limited access to food safety monitoring remain pressing concerns (Ward et al., 2022; Koch et al., 2021). Opportunities and Challenges in Seaweed Livelihoods (LMICs)

Opportunities and Challenges in Seaweed Livelihoods (LMICs)

Domain	Opportunities	Challenges
Farming/ Production	- Ideal for many LMIC coastal zones -Women-led microenterprises possible -Supports pollution control	-Lack of technical training -Limited public research -Seasonal labor and climate variability

Processing & Value Addition	-Potential to boost income through food, cosmetic & pharma sectors -Expands rural jobs post-harvest	- High cost of processing units -Weak supply chains and infrastructure - Food safety issues
Export Trade	- Global demand is rising - Can become a new export commodity	-Poor regulation - Few species are premium prices -Limited data on local capacity
Consumption & Nutrition	-Rich in micronutrients -Can improve local diets in coastal areas	- Low calorie content -Expensive relative to vegetables -Cultural unfamiliarity

3. Mariculture and Aquaculture

Mariculture the production of sea species in coastal and open ocean habitats has become an essential solution to global food and nutrition security. As wild fish stocks plateau, mariculture now accounts for one-third of total aquaculture production and more than half the seafood eaten worldwide.

A recent international study assessed 117 coastal countries with a Mariculture Opportunity Index identifies its unrealized potential, particularly in island countries of Southeast Asia and the Caribbean, where there is high seafood dependency and malnutrition persists. Aligning the development of mariculture with nutritional and economic objectives, these countries can derive substantial benefit. Yet, for this to be maximized, the challenges of limited governing frameworks, underinvestment and ensuring local consumption of mariculture products need to be addressed. Mariculture therefore promises not just as a source of food but also as a route to coastal livelihood resilience and national nutritional enhancement (Liu et al.,2024).

Open sea cage farming, oyster and mussel culture and Integrated Multi Trophic Aquaculture (IMTA) are becoming popular in India's coastal regions. Cage rearing of fish such as seabass and cobia can produce ₹1.5 to ₹4 lakhs per cycle, while mussel culture in Kerala is highly rewarding with low land usage. IMTA systems increase environmental sustainability as they integrate fish, seaweed and shellfish farming in a harmonized ecosystem (Gopalakrishnan, 2017).

In Lakshadweep and the Andaman and Nicobar Islands, CMFRI is spearheading research to develop location-specific fishery management plans and mariculture models. These include sea cage farming, black-lip pearl culture and seaweed cultivation, tailored to local environmental and socio-economic conditions (Parappurathu et al., 2017).

4. Pearls, Ornamental Fish and Tourism

Ornamental fish farming and pearl culture present low-space, high-yielding opportunities, particularly for women and youth. These activities present home-based sources of income with small ecological impact. Similarly, recreational fishing and ecotourism, regulated and linked with community-based tourism networks, can also earn alternative incomes while supporting marine conservation (Ali et al., 2023).

5. National Strategies for Sustainable Marine Futures

Indian Council of Agricultural Research - Central Marine Fisheries Research Institute (ICAR-CMFRI), National Institution for Transforming India Aayog (NITI Aayog) and World Wide Fund for Nature (WWF) -India's joint effort is a turning point towards aligning India's marine fisheries with UN Sustainable Development Goal 14 (SDG-14). The major policy suggestions are:

- Halting new fishing vessel registrations to prevent overcapacity
- Implementing uniform Minimum Legal Size (MLS) regulations across coastal states
- Licensing fishing gears and boatyards
- Establishing marine protected areas and no-take zones

- Promoting Vessel Monitoring Systems (VMS)
- Incorporating marine literacy into school curricula (CMFRI-NITI Aayog Report, 2017)

CMFRI's *Theeranaipunya* project, in partnership with the Society for Assistance to Fisherwomen (SAF), equips young fisherwomen in Kerala with skills in communication, entrepreneurship and higher education pathways. With stipends and experiential learning, the program builds employability and leadership among coastal women (Salim, 2019).

Coastal Cleanliness and Awareness

Under the "Swachh Samundar Abhiyaan", CMFRI launched coastal clean-up drives and educational campaigns to reduce plastic waste in marine environments.

Source:https://www.thehindu.com/news/cities/Kochi/fish-cemetery-bags-swachh-bharat-award/article23166224.ece

Innovative installations like the "Fish Cemetery" have sparked public awareness, earning national accolades for CMFRI's Swachh Bharat initiatives (Parappurathu et al., 2017). The Fish Cemetery, an art installation set up by the Central Marine Fisheries Research Institute (CMFRI) to create awareness on coastal pollution, has won national recognition with the CMFRI bagging the Swachh Bharat Award in 2018.

Conclusion

Through deep-sea ventures, sustainable aquaculture, women-led entrepreneurship and forward-looking policy, India's coastal fishers are being equipped to face the dual challenges of livelihood security and environmental conservation. Institutions like CMFRI play a pivotal role in transforming marine resource use into models of resilience and sustainability, ensuring that the blue economy benefits both people and the planet.

References

1. Ahmad, Zuriyati & Azlan, & Razak, Wan Maziah Wan & Zahari, Ahmad & Abdul-Rahman, Baharom & Tinik, Ramli. (2021). Coastal Fishermen's Quality of Life in Kuala Dungun: A Study of Income and Household Expenditure. International Journal of Academic Research in Business and Social Sciences. 11. 10.6007/IJARBSS/v11-i18/11627.
2. Ali, Bilame & Ngusa, (2023). 'Alternative Livelihood Practices Engaged by Artisanal Fishers for Household Improvements in Zanzibar Islands'. Journal of Interdisciplinary Socio-Economic and Community Study, Volume 03, Number 2, Pages 45-54. Universitas Brawijaya. DOI: http://dx.doi.org/10.21776/ jiscos.03.2.01
3. Asiedu, Berchie & Nunoo. (2013). Alternative Livelihoods: A Tool for Sustainable Fisheries Management in Ghana. International Journal of Fisheries and Aquatic Sciences. 2. 21-28.
4. Gopalakrishnan & Ignatius, Boby & Suresh, Vettath. (2022). Mariculture Development in India: Status and Way Forward. Indian Journal of Plant Genetic Resources. 35. 317-321. 10.5958/0976-1926.2022.00091.2.
5. Hamad, Waziri & Islam, Gazi Md Nurul. (2022). The Role of Livelihood Assets on the Improvement of the Livelihoods of Fisher Households in Zanzibar. American Journal of Environmental and Resource Economics. 7. 25. 10.11648/j.ajere.20220701.14.
6. Islam, Begum, Rahman and Ullah (2021) Seasonal Fishery Closure in the Northern Bay of Bengal Causes Immediate but Contrasting Ecological and Socioeconomic Impacts. Front. Mar. Sci. 8:704056. doi: 10.3389/fmars.2021.704056

7. Koch et al., 2021. The Role of Seaweed in the Future Food System: the Potential of Dutch Parties in This Young Sector. Report to the Dutch Ministry of Agriculture, Nature and Food Quality (2021)
8. Liu, Chang & Liu, Gengyuan & Cristiano, Silvio & Ulgiati, Sergio & Xu, Linyu & Yang, Zhifeng. (2024). Investigating Potential Ecological Benefits From Mariculture. Earth's Future. 12. 10.1029/2023EF003766.
9. Parappurathu, George, Narayanakumar, Aswathy, Ramachandran & Gopalakrishnan, (2017). *Priorities and strategies to boost incomes of marine fisher folk in India*. **Agricultural Economics Research Review**, 30(Conference Numbe, 205–216. https://doi.org/10.5958/0974-0279.2017.00035.0
10. Rahaman, Samanta, Banerjee, Dash, Giri, Das, Ali, and Mondal. (2021). Socio demographic profile, nutritional and health status of fishermen: A review. In Bangladesh Journal of Medical Science (Vol. 20, Issue 4, pp. 707–713). Ibn Sina Trust. https://doi.org/10.3329/bjms.v20i4.54124
11. Rajasree, & Gayathri.(2014). Women enterprising in seaweed farming with special reference to fisherwomen widows in Kanyakumari District, Tamil Nadu, India. *Journal of Coastal Development*, 17(1), 1000383. https://doi.org/10.4172/1410-5217.1000383
12. Ratheesh & Meharoof, Mohammed & Albert Christy, Albin. (2023). Sustainable Development Goals and Fisheries Sector: Progressing Towards a Sustainable Future. 6. 12 25.
13. Salim, Joseph, James, Shinu, Athira, N. R., & Smitha, (2019). *Assessing the alternative livelihood options for climate change vulnerable coastal fishing villages in Kerala, India*. **International Journal of Environment and Climate Change**, 9(4), 204–216. https://doi.org/10.9734/ijecc/2019/v9i430096
14. Sukono, Riaman, Herawati, Saputra, & Hasbullah. (2021). Determinant factors of fishermen income and decision-making for providing welfare insurance: An application of multinomial logistic regression. Decision Science Letters, 10(2), 175–184.
15. Treakle, Abbott, & Holland, D. S. (2023). Not by fishing alone: Non-fishing employment and income for US West Coast fishers. Ocean & Coastal Management, 243, 106763.
16. Tripathy, Ramasubramanian, Krishnan and Ananthan. A Study On The Comparison Of Income Between Fishing Activity And Alternative Livelihood Of Rushikulya Fishers, Odisha., J. Exp. Zool. India Vol. 22, No. 1, pp. 569 572, 2019 www.connectjournals.com/jez ISSN 0972 0030
17. Ward et al., 2022. Ward, Kambey, Faisan, Tan, Daumich, Matoju, Stentiford, Bass, Lim, Brodie, Poong. Ice-Ice disease: an environmentally and microbiologically driven syndrome in tropical seaweed aquaculture.Rev. Aquacult., 14 (1) (2022), pp. 414-439, 10.1111/raq.12606
18. Webb, Somers & Thilsted, S. H. (2023). Seaweed's contribution to food security in low- and middle-income countries: Benefits from production, processing and trade. *Global Food Security, 37,* 100686. https://doi.org/10.1016/j.gfs.2023.100686

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Spirulina Hydrolysate: Bioactive Properties and Potential Application

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Spirulina is widely used as nutraceutical food supplement worldwide. Currently, there is an increase in interest towards the consumption of foods rich in bioactive compounds. Spirulina is a multicellular, filamentous, blue green microalgae which is rich in various bioactive compounds and it is also used as a protein source for human nutrition. Spirulina is also called as a "Super food". The two most popular species of spirulina are *Spirulina platensis* and *Spirulina maxima*. The cell wall of spirulina is made up of easily digestible polysaccharides which makes them to highly absorbable by the human body. Spirulina has been also explored for a source of different bioactive peptides. In this context, this article highlights the bioactive properties and potential applications of spirulina and its bioactive peptides.

Chemical and bioactive properties of Spirulina

Spirulina is rich in protein, vitamins, essential fatty acids, mineral and carbohydrates. Additionally, it has plenty of antioxidants. The dried spirulina has a protein content of 50-60%. Spirulina contains a major protein called phycobilin. Phycobilin consists of three major protein includes phycocyanin, allophycocyanin and phycoglobin (Hsieh-Lo et al., 2019). Spirulina contains about 38-47% essential aminoacids (EAA). The major aminoacids present in the spirulina includes leucine, valine and isoleucine. The Spirulina contains all the essential vitamins includes vitamin A, vitamin D, vitamin E, vitamin K and vitamin B (riboflavin,niacin, pantothenic acid, pyridoxine, folic acid and cobalamin). Spirulina has a lipid content of 4–7%. Major fatty acids found in spirulina includes palmitic acid, palmitoleic acid, myristic acid, oleic acid, linoleic acid, gamma-linolenic acid, stearidonic acid, arachidonic acid, eicosapentaenoic acid (EPA) and docosapentaenoic acid (DHA). Spirulina contains 13.6% carbohydrates and it has diverse carbohydrates includes glucosamine, rhamnosamine, glucogen polymer, glucose, fructose, sucrose, glycerine, xylose, galactose and mannitol. Spirulina has 8% mineral content. The major minerals found in spirulina includes potassium, calcium, chromium, copper, iron, manganese, magnesium, phosphorus, selenium, sodium, boron, molybdenum and zinc. The spirulina contains less than 1% pigments which includes Alpha and beta-carotenes, xanthophylis, echinenone, cryptoxanthin, zeaxanthin and lutein, porphyrin, chlorophyll, phycocyanin, phycoerythrin, phytonadione and tetrapyrrole. Spirulina is found have antioxidant, antimicrobial, anti-inflammatory, immunomodulatory, Hypoglycaemic, Hypolipidemic, anti-viral and anti-cancer activities. Spirulina also has a pre and probiotic impact due to its high oligosaccharide content, which encourage the development of intestinal microbiota. Pyocyanin and carotenoids (beta-carotene, xanthin, orangetin) content in spirulina plays vital role in antioxidant and anti-inflammatory activity. Polysaccharide present in the spirulina provides antibacterial, antiviral and anti-cancer properties.

Spirulina Hydrolysate

Spirulina hydrolysate is prepared from spirulina by enzymatic or chemical method of hydrolysis. This hydrolysis process improves the bioavailability and absorption of nutrients present in spirulina, making them more easily utilised by the body. Enzymatic hydrolysis can transform microalgal proteins into molecules with increased value and superior functional characteristics, such as antioxidant peptides (APs), antihypertensive peptides, and antibacterial peptides. The major enzyme explored for hydrolysis of spirulina includes papain, pepsin, pancreatin, trypsin, alcalase, flavorzyme etc. Hydrolysates of Spirulina have been shown to have strong antioxidant activity, as well as a range of potentially beneficial health effects, such as anticancer, blood pressure reduction, blood cholesterol reduction, immune system strengthening, and probiotic effects.

Bioactive properties of Spirulina Hydrolysate

The peptides present in protein hydrolysate found to have antioxidant activity. The antioxidant activity of protein hydrolysates depends on amino acids and peptides composition in protein hydrolysates. Spirulina hydrolysates are found to have hydrophobic amino acids, such as Proline, Leuicine, Alanine, Trptophan and Phenylalanine are believed to possess high antioxidant activity. Table 1 shows amino acid sequence of peptide derived from spirulina and its bioactivities. Spirulina hydrolysate is found to have Angiotensin-1-converting enzyme (ACE) inhibitory peptide. Angiotensin is a peptide hormone that can constrict the blood vessels and increase blood pressure in the cardiovascular system. The mechanism of action of peptide derived from spirulina are given in table 2.

Table 1: Bioactive peptide derived from Spirulina

Amino acid sequence	Enzyme used for hydrolysis	Species used	Bioactivity
Leu-Asp-Ala-Val-Asn-Ar	Trypsin, α-chymotrypsin and pepsin	*Spirulina maxima*	Anti-inflammatory
Ala-Glu-Leu	Pepsin	*Spirulina platensis*	Anti-hypertensive
Ile-Gln-Pro	Alcalase	*Spirulina platensis*	Anti-hypertensive
Val-Glu-Pro	Papain	*Spirulina platensis*	Anti-hypertensive
Thr-Asp-Pro-Ile-Ala-Cys	Alcalase , Flavourzyme	*Spirulina platensis*	Iron-chelating activity

Table 2: Bioactive peptide properties and its mechanism of action

Bioactive properties	Mechanism of action
Antioxidant activity	Reduce the oxidative hemolysis of erythrocyte, reduce the production of malonaldehyde, scavenging free radicals
Anti-inflammatory activity	Inhibit the endothelial cell inflammation, inhibit the reactive oxygen species (ROS), resistant to inflammation of different tissues)
Cholesterol-lowering activity	Reduce the serum cholesterol
Hypoglycemic activity	Improve the Insulin regulation. Reduce the oxidative stress in urine and kidneys
Antidiabetic activity	Inhibit dipeptidyl peptidase IV (DPP-IV)
Hypotensive activity	Inhibit angiotensin converting enzyme activity
Antiallergic activity	Inhibit the mass cell degranulation, inhibit the cytokine production
Anticancer activity	Improve the cell oxidative pressure, remove the superoxide anion and hydroxy radical

Potential applications:

Spirulina contains all essential nutrients which finds various applications includes agriculture, food Industry, pharmaceuticals and cosmetic Industry (Matos et al., 2020). In food industry spirulina has been used to develop various food products such as cookies, crackers, ice cream, soft cheese, pasta, soup and yogurt etc. The spirulina is added in the food products either free or encapsulated form. Encapsulation is a process of coating solid, liquid or gaseous materials with suitable carrier which release the active ingredient in desired site. Encapsulation process protect the bioactive peptide from thermal and oxidative degradation. The lutein and carotenoids present in the spirulina has anti-aging effect which finds applications in cosmetic formulations (Lucas et al., 2018). Unlike free spirulina, bioactive peptides derived from spirulina also found to have application in food, pharmaceutical and cosmetic applications. It has been reported that peptides derived from spirulina act as a functional ingredient in foods and pharmaceuticals against inflammatory diseases, treatment of hypertension, or as novel inhibitor of allergic reactions. Moreover, peptide with iron-chelating activity can be used as iron supplement.

Recommendation of intake of Spirulina

World Health Organization (WHO) has approved that spirulina as a nutrient rich food due to its high protein and iron content. It also named spirulina as a "Super food". US Food and Drug Administration (FDA) has given approval for spirulina as "generally recognised as safe" (GRAS) (Villaró-Cos et al., 2024). The European Food Safety Authority (EFSA) and the Scientific Committee on Food (SCF) also recommend 10 g of *S. platensis* as a supplement for daily intake to protect the health of humans, and research indicates that there is no risk with these microalgae use as a food. According to National Cancer Institute of the United States research, intake of 4 gram of spirulina per day, or 6 mg of beta-carotene, can reduce the risk of developing cancer. (Ranga et al., 2010). However, the research on intake of hydrolysed is not well established and its research is underway.

Conclusion

Spirulina is reasonably accepted as a functional ingredient in food, pharmaceutical and cosmetics. Spirulina also serve as a novel source for extracting its bioactive peptide. However, the potential of extraction of peptide from spirulina is not well explored. Currently, only 12 different bioactive peptides are isolated and characterized. There is an opportunity to explore more peptide with various bioactivity of spirulina. Moreover, these peptides can be used as functional ingredient in food and pharmaceuticals. Most of the bioactivity of peptide derived from spirulina and other food sources are tested in animal models. Only, very few health claims is accepted and are listed in European commission regulations (EU) 432/2012 for bioactive peptide derived from spirulina. More studies are required to human intervention demonstrating the health benefits of consuming Spirulina-derived peptides and hydrolysates will boost the use of these ingredients in the food and functional food industries.

References

1. Villaró-Cos, S.; Guzmán Sánchez, J.L.; Acién, G.; Lafarga, T. Research Trends and Current Requirements and Challenges in the Industrial Production of Spirulina as a Food Source. Trends Food Sci. Technol. 2024, 143, 104280.
2. Siramdas Sahil, Suman Bodh∗ and Praveen Verma .2024. Spirulina platensis: A comprehensive review of its nutritional value, antioxidant activity and functional food potential . Journal of Cellular Biotechnology 10: 159–172
3. Hsieh-Lo M, Castillo G, Ochoa-Becerra MA, Mojica L. Phycocyanin and phycoerythrin: Strategies to improve production yield and chemical stability. Algal Research. 2019;42:101600.
4. Jung F, Kr¨uger-Genge A, Waldeck P, K¨upper JH. Spirulina platensis, a super food? Journal of Cellular Biotechnology.2019;5(1):43-54.
5. Matos,J.; Cardoso, C.L.; Falé, P.; Afonso, C.M.; Bandarra, N.M. Investigation of Nutraceutical Potential of the Microalgae Chlorella Vulgaris and Arthrospira platensis. Int. J. Food Sci. Technol. 2020, 55, 303–312
6. Lucas, B.F.; de Morais, M.G.; Santos, T.D.; Costa, J.A.V. Spirulina for Snack Enrichment: Nutritional, Physical and Sensory Evaluations. LWT—Food Sci. Technol. 2018, 90, 270–276.
7. Ovando, C. A., Carvalho, J. C. de, Vinícius de Melo Pereira, G., Jacques, P., Soccol, V. T., & Soccol, C. R. (2016). Functional properties and health benefits of bioactive peptides derived from *Spirulina*: A review. *Food Reviews International*, *34*(1), 34–51.
8. Aysun Y and Beraat O. 2016. Bioactive Peptides Isolated from Microalgae *Spirulina platensis* and their Biofunctional Activities. Akademik Gıda. 14. 412-417.

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Hydroponic Technology for Cultivation of Fruit Crops

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Hydroponics is the technique of growing crops without soil. The term "hydroponics" comes from Latin and means "working water." In the absence of soil, water serves to deliver nutrients, hydration, and oxygen to plants. Hydroponics allows plants to grow, fruits vegetable gardening and ornamentals flowers like orchids. Hydroponic gardens produce gorgeous fruits and flowers in half the time by using 90% less water than conventional agriculture and innovative design. Hydroponic fruit production is a way of growing fruits in a controlled environment in which the plants obtain vital nutrients from a nutrient-rich solution rather than dirt. This technology has gained popularity in recent years due to its ability to boost crop yields, minimize water consumption, and improve fruit quality. Hydroponics enables for fine control of growing conditions, allowing growers to tailor the environment to certain fruit crops.

Introduction

Hydroponics is a method of growing plants in a nutrient solution (which contains water fertilizers) with or without the addition of an artificial medium (sand, vermiculite, perlite, gravel, rockwool, or peat mass) to give mechanical support. Using this technology, the roots absorb balanced nutrients dissolved in water, meeting all of the plant's developmental requirements. This approach is particularly beneficial in areas where environmental stress (cold, heat, desert, etc.) is a significant issue. It is gaining popularity since there is no risk of soil-borne disease, bug, or pest infection in the crops. Photosynthesis is a process that plants use to sustain themselves. Chlorophyll, a green pigment found in plants' leaves, helps them collect sunlight. They use light energy to break water molecules that they absorb through their root systems. Hydrogen molecules interact with carbon dioxide to form carbohydrates, which are needed by plants for nourishment. Oxygen is subsequently released into the atmosphere, which helps to keep our world habitable. Plants do not require soil for photosynthesis. r fertilizers), with or without the use of an artificial medium (sand, vermiculite, perlite, gravel, rockwool, peat mass) for mechanical support. Using this technology, the roots absorb balanced nutrients dissolved in water, meeting all of the plant's developmental requirements. They require soil to provide water and nutrients. When nutrients dissolve in water, they can be given directly to a plant's root system by flooding, misting, or submersion. Hydroponic developments have demonstrated that direct exposure to nutrient-rich water is a more effective and versatile technique of growth than standard irrigation. Controlling the plant's environment lowers numerous risk factors. Plants cultivated in gardens and fields are subjected to a number of stressors that harm their health and growth. Fungi in the soil can transmit disease to plants. Rabbits and other wildlife can harm crops grown in your garden. Pests like locusts can fall on crops and decimate them in the afternoon. Hydroponic systems eliminate the unpredictable nature of growing plants outdoors and on Earth. Seedlings mature faster when there is no mechanical resistance in the soil. Hydroponics produces healthier and higher quality fruits and vegetables because pesticides are not used. Without limitations, plants can develop at an increasing rate.

Growing Media for Hydroponics:
Hydroponic plants are often grown in inert media that sustain the plant's weight. Growing medium is a substitute for soil, but it does not supply independent nutrients to the plant. Instead, this porous medium holds onto moisture and nutrients from the nutrition solution it carries to the plant. Many growing media are pH-neutral, which means they will not disrupt the nutrient solution's balance. There are numerous media options available, and the specific plant and hydroponic system will determine which is ideal for your project. Hydroponic growth media is commonly available, both online and in local nurseries and garden stores.

Types of Hydroponic Systems in Solution Culture

1. **Wick system:** This is simplest hydroponic system requiring no electricity, pump and aerators. Plants are placed in an absorbent medium like coco coir, vermiculite, perlite with a nylon wick running from plant roots into a reservoir of nutrient solution. Water or nutrient solution is supplied to plants through capillary action. This system works well for small plants, herbs and spices.
2. **Deepwater culture (DWC)**: In deep water cultures, roots of plants are suspended in nutrient rich water and air is provided directly to the roots by an air stone. Hydroponics buckets system is classical example of this system. Plants are placed in net pots and roots are suspended in nutrient solution where they grow quickly in a large mass. It is mandatory to monitor the oxygen and nutrient concentrations, salinity and pH as algae and moulds can grow rapidly in the reservoir. This system work well for larger plants that produce fruits especially cucumber and tomato, grow well in this system.
3. **Drip system**: In this system, the nutrient solution is set apart in a reservoir, and the plants are grown separately in a soilless medium. Water or nutrient solution from the reservoir is provided to individual plant roots in appropriate proportion with the help of pump. Drip systems dispense nutrients at a very slow rate, through nozzles, and the extra solutions can be collected and recirculated, or even allowed to drain out. With this system, it is possible to simultaneously grow several kinds of plants.
4. **Ebb and flow**: This is first commercial hydroponic system which works on the principle of flood and drain. This system utilizes a grow tray and a reservoir that is filled with a nutrient solution. A pump periodically floods the grow tray with nutrient solution, which then slowly drains away. it is possible to grow different kinds of crops but the problem of root rot, algae and mould is very common therefore, some modified system with filtration unit is required
5. **Nutrient film technique (NFT):** NFT was developed in the mid1960s in England by Dr. Alen Cooper to overcome the shortcomings of ebb and flow system. Similar to aeroponics, the nutrient film technique (NFT) is the most popular hydroponic system. In this method, a nutrient solution is pumped constantly through channels in which plants are placed. When the nutrient solutions reach the end of the channel, they are sent back to the beginning of the system. This makes it a recirculating system, but unlike DWC, the plants roots are not completely submerged, which is the main reason for naming this method NFT.
6. **Aeroponics systems:** This technology suspends plants in the air, exposing their naked roots to a nutrient-rich mist. Aeroponics systems are enclosed structures, such as cubes or towers, that can house several plants simultaneously. Water and nutrients are held in a reservoir and then injected into a nozzle, which atomizes the solution and disperses it as a thin mist. The mist normally exits the top of the tower,

allowing it to descend into the chamber. Some aeroponics mist plant roots continuously, while NFT systems constantly expose the roots to a nutrient film. Others operate more like an ebb and flow system, misting the roots in the gaps. Aeroponics doesn't need substrate medium to thrive. The roots' constant exposure to air allows them to absorb oxygen and grow at a faster rate. Aeroponic systems utilize less water than any other type of hydroponics. In fact, growing a crop aeroponically requires 95% less water than an irrigated field. Their vertical structure is intended to take up little space and allow several towers to be put in the same area. Even in constrained spaces, good yields can be obtained with aeroponics. Furthermore, because of their increased exposure to oxygen, aeroponic plants grow quicker than hydroponically cultivated plants. Aeroponics allows simple harvesting throughout the year. Vine plants and nightshades such as tomatoes, bell peppers, and eggplants all perform well in an aeroponic environment. Lettuce, baby greens, herbs, watermelon, strawberries and ginger all thrive here as well. However, fruiting trees are too large and heavy to be grown aeroponically, and plants with extensive root systems such as carrots and potatoes cannot be grown underground.

Benefits of Hydroponic Fruit Production

The benefits of hydroponic fruit production include:

- **Increased crop production and yields:** Hydroponics can increase fruit production by up to 30% compared to traditional soil-based farming methods.
- **Conservation of Water:** Hydroponics uses significantly less water than traditional farming methods, making it an attractive option for water-scarce regions.
- **Fruit quality Improvement:** Hydroponics allows for exact control over growing conditions, allowing farmers to adjust the environment for certain fruit crops, resulting in higher fruit quality and a longer shelf life.
- **Reduced land use:** Hydroponics can be used in a variety of settings, including indoor facilities, reducing the need for large areas of land.
- **Better growth rate:** If you give a plant exactly what it needs and when it needs, the plant is likely to grow as healthy as genetically possible. In hydroponics, this is exactly the case as it is very much possible to create an artificial environment with the addition of a light or air conditioning in an area enclosed between four walls. As the environment created will be suited best according to the different plant's needs, they will give better results in terms of turning out to be fresher, greener and tastier to eat.
- **Farming at heights:** Farming at heights means that less space is used to generate a high amount of outputs. This is possible via the fact that hydro farms extended vertically in even places such as marginal lands, inside warehouses, water scarce areas. This is not possible with geoponics for obvious reasons and thus if comparing both the situations then it can be evident that per cubic feet of hydroponics generates more output turning out to be more profitable and fruitful

Challenges and Limitations of Hydroponic in Fruit Production

While hydroponic fruit production offers many benefits, there are also several challenges and limitations to consider, including:

- **High initial investment**: Setting up a hydroponic system can be expensive, requiring a significant initial investment in equipment and infrastructure.
- **Energy consumption**: Hydroponic systems require a significant amount of energy to power the pumps, lights, and other equipment. Vulnerable to power outages. Both passive and active hydroponics systems depend on electricity to power the different components such as grow lights,

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- water pumps, aerators, fans, etc. Therefore, a power outage will affect the entire system. In active systems, a loss of power can be detrimental to plants if it goes unnoticed by the grower.
- **Limited crop selection**: Not all fruit crops are well-suited to hydroponic production, and some may require specialized equipment or growing conditions.
- **Requires constant monitoring and maintenance:** Hydroponics requires a higher level of monitoring and micro-managing than growing plants traditionally. To maintain a carefully controlled growing environment, all system components need constant vigilance-lights, temperature, and many aspects of the nutrient solution such as pH and electrical conductivity. The nutrient solution also needs to be flushed and replaced regularly, and the system parts cleaned often to prevent buildup and clogging.
- **Waterborne diseases**: Because hydroponically grown plants are grown in water instead of soil, waterborne diseases are considerably higher. With the water circulating continuously through the system, infections can spread quickly throughout the growing system as a whole, affecting the whole collection of plants. In extreme cases, a waterborne disease can kill all the plants in a hydroponics system within hours.

Conclusion

Hydroponics is the fastest-growing sector, and it has the potential to dominate future food production. Hydroponics is one of the technologies with the potential to double farmers' income. In the shifting landscape of food consumption, hydroponics technology will play an important role in ensuring sustainable and year-round production in urban and periurban settings. Hydroponic fruit cultivation is a promising way to boost crop yields, save water, and improve fruit quality. While there are some advantages to this strategy, there are some drawbacks and restrictions to consider. As population grows and land management deteriorates, people will resort to innovative technologies such as hydroponics and aeroponics to generate new channels of crop production. Due to rapid urbanization and crowded cities without gardens, we have no choice but to use soil-less culture to help improve the production and quality of produce in order to ensure our country's food security. Hydroponic and soilless culture can be described as "the next logical step" following traditional agriculture. Additional study is required to fully explore the possibilities of hydroponic fruit production and to build more efficient and sustainable systems.

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Empowering Rural Women Through the Krishi Sakhi Convergence Programme for Sustainable Agriculture and Rural Development

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The upliftment of women in India is critical in achieving gender equity, economic advancement and social development. It helps women to get access to education, employment and even positions of authority while shattering the walls of bias and discrimination towards women. The Krishi Sakhi Convergence Programme (KSCP) offers rural women innovative training opportunities on skill development, sustainable farming and achieving optimal socio-economic status. This program appreciates women's roles in agriculture by equipping them with managerial knowledge, modern farming practices and basic leadership skills to operate as Krishi Sakhis, or community-based providers of agricultural advice services. KSCP organizes soil health management, organic farming, water management and climate smart agriculture technology as these topics are vital for women farmers. This initiative empowers women while simultaneously enhances the rural agriculture ecosystem by bridging the knowledge gap and creating a sustainable technology infusion culture. It also provides women better access to government schemes, finances and market linkages to ensure optimal economic engagement among rural women. By applying science to traditional knowledge, KSCP ensures inclusive growth, enhancement of agricultural productivity and food security at the lowest levels. This paper reviews the role of Krishi Sakhi Convergence Programme, its contribution to eco-friendly farming and its wider effects on the resilience of the rural economy.

Keywords: Women empowerment, gender equity, rural development and Krishi Sakhi Convergence Programme (KSCP)

Introduction

Women empowerment is essential for achieving sustainable development and social justice. Empowered women contribute to the betterment of their families, communities and nations, leading to sustainable development and prosperity (Das, 2024) (Khulbe & Joshi, 2024). The importance of women empowerment has been emphasised in the recent Sustainable Development Goals (SDG) defining the global development agenda for the 2015-2030 horizon (United Nations, 2015). Women's engagement in agricultural development is pivotal in strengthening rural economies, as it greatly improves productivity, economic progress and alleviation of poverty. Even with numerous hurdles output and women mostly do a mix of activities ranging from crop production to animal husbandry. Not only does this improve agricultural productivity but enhances the economic status of families living in rural areas. On the other hand, a lack of access to resources and decision-making authority tends to inhibit output women from reaching their full potential. Women's participation in agriculture is linked to increased productivity and technical efficiency. For instance, in Pakistan, women's involvement in rice production improved technical efficiency by 47.30 % (Rasheed *et al.*, 2020). In India, women contribute significantly to various agricultural sectors, including dairy, poultry and forestry, despite being underrepresented in employment and pay (Pradhan et al., 2024). Women face obstacles such as limited access to land, credit and technology, which restrict their ability to contribute fully to agricultural development (Pradhan *et al.*, 2024). This paper examines the key components of the KSCP, its role in fostering women-led agricultural development and its contribution to sustainability and rural economic growth.

Objectives of KSCP

The Krishi Sakhi Convergence Programme (KSCP), launched on August 30, 2023, is a collaborative initiative of the Ministry of Agriculture and Farmers Welfare (MoA & FW) and the Ministry of Rural Development (MoRD). It is part of the broader Lakhpati Didi initiative, which aims to empower three crore rural women to earn at least ₹1 lakh annually through diversified livelihoods (Press Information Bureau, 2024; Statetimes, 2025). KSCP is designed to address the persistent gaps in agricultural extension services, especially in underserved rural areas, by leveraging local women as trained Krishi Sakhis or para-extension workers. The program uses a multi-pronged strategy with the following key objectives:

- **Skill Development:** KSCP offers an intensive 56-day training programme that covers the entire agricultural cycle from land preparation to harvesting. The training enhances both technical and managerial competencies, enabling women to independently manage farm operations and offer advisory services (The Times of India, 2024).
- **Knowledge Infusion:** By integrating scientific farming practices with traditional ecological knowledge, the program aims to enhance farm productivity sustainably. As of now, only about 4.00 % of Indian farmers are reported to use sustainable methods like natural or organic farming (Gupta *et al.,* 2021) and KSCP strives to increase this number through field-level interventions.
- **Economic Empowerment:** KSCP positions women as central economic actors in agriculture by linking them to government schemes, financial institutions and market channels. As per Accion Advisory (2025), 55.50 % of bank accounts in India are now held by women, but rural women still face significant challenges in accessing formal credit. KSCP helps bridge this gap.
- **Sustainable Agriculture:** The program emphasizes soil health management, organic inputs, climate-smart agriculture and efficient water use. These interventions are crucial, considering that only about 2.00 % of India's agricultural land is certified as organic (Gupta *et al.,* 2021).
- **Community Engagement:** A major strength of KSCP lies in building a nationwide network of trained Krishi Sakhis. As of mid-2024, over 34,000 women have been trained and certified, aiming for a target of 70,000 (Statetimes, 2025). These women act as trusted messengers of scientific knowledge and catalysts of rural transformation.

Training and Capacity Building

KSCP's structured training approach aims to empower women with both knowledge and field-level application skills. Delivered under the Deendayal Antyodaya Yojana – National Rural Livelihoods Mission (DAY-NRLM) framework, training modules are implemented in collaboration with national institutions like MANAGE, KVKs and State Rural Livelihoods Missions.

Key components of the training curriculum include:

- **Soil Health Management:** Trainees learn how to conduct soil testing, apply bio-fertilizers and manage nutrients organically. This enhances productivity and soil resilience, particularly important in regions experiencing soil degradation (The Times of India, 2024).
- **Climate-Smart and Organic Farming:** Modules emphasize practices like crop rotation, mulching, integrated pest management (IPM) and efficient irrigation. Currently, IPM adoption in India remains limited, covering only around 5 million hectares (Gupta *et al.,* 2021).

- **Market and Financial Linkages:** The training connects women with Self-Help Groups (SHGs), cooperatives and direct market platforms. As of 2024, over 10.04 crore women are organized into 90.76 lakh SHGs under DAY-NRLM (Ministry of Rural Development, 2024), offering a strong institutional backbone for market access.
- **Leadership and Advocacy Skills:** KSCP emphasizes leadership development, encouraging women to engage in decision-making roles in Panchayats, FPOs and local agricultural planning.

Upon successful completion of training and evaluation, participants are certified as Krishi Sakhis, eligible for formal engagement as para-extension agents. They receive performance-based incentives for delivering services like training, awareness drives and farmer advisory under various government schemes (PIB, 2024).

Impact on Women and Rural Development

The KSCP has had transformative effects across economic, social and ecological dimensions of rural development:

- **Income Generation:** Certified Krishi Sakhis are earning between ₹60,000 – ₹80,000 per year, supplementing household incomes and improving financial security (PIB, 2024; The Times of India, 2024). This income comes from service-based incentives and agri-enterprise activities.
- **Gender Equity in Agriculture**: Although 75.00 % of rural women are involved in agriculture, they own only about 13% of agricultural land in India (Women's Earth Alliance, 2022). By equipping women with skills and visibility, KSCP helps challenge patriarchal norms and improve access to decision-making spaces.
- **Yield Improvement and Knowledge Transfer:** On average, farms managed by women yield 20.00 –30.00 % less due to reduced access to inputs and advisory (Women's Earth Alliance, 2022). KSCP helps bridge this gap by building technical capacity and supporting peer-to-peer learning.
- **Strengthening the Rural Economy:** By integrating trained women into SHGs and Farmer Producer Organizations (FPOs), KSCP contributes to the creation of community-level enterprises and diversification of livelihoods. These networks promote resilience and collective bargaining power (MoRD, 2024).
- **Environmental Sustainability:** Women trained under KSCP adopt low-input, resource-efficient practices that reduce environmental degradation, conserve water and improve soil health. This is crucial given the growing stress on India's natural resources (Cassen, 2004).

Collaboration and Sustainability

KSCP's strength lies in its convergent model, bringing together multiple actors and policies to ensure long-term sustainability:

- **Government Partnerships:** The MoA & FW and MoRD provide policy oversight, funding and integration with existing schemes like Soil Health Card Mission, Paramparagat Krishi Vikas Yojana (PKVY) and Mission Organic Value Chain Development (PIB, 2024).
- **NGOs and Training Partners:** Implementation support is provided by civil society groups and institutions like MANAGE, who deliver standardized curricula and ensure quality training (The Times of India, 2024).
- **Community-Based Organizations (CBOs):** The existing SHG network ensures grassroots mobilization. With over 9 million SHGs active across India, KSCP can leverage their scale to institutionalize women-led agricultural development (MoRD, 2024).

This convergence ensures a bottom-up and self-sustaining model, where trained women reinvest knowledge in their communities and local governance bodies support continued capacity building.

Challenges and Future Directions

Despite promising outcomes, several structural and operational challenges hinder KSCP's full potential:

- **Digital Divide:** Although 60.00 % of Indian women own mobile phones, digital literacy and usage for agriculture remain low (Kejriwal & Bharadwaj, 2025). Expanding mobile-based advisory tools and local-language agri-apps is essential.
- **Socio-Cultural Norms:** Women's restricted land ownership (13.00 %) and decision-making power limit their formal participation in agriculture (Women's Earth Alliance, n.d.). Legal and policy reforms ensuring joint land titles, inheritance rights and women-centric extension policies are critical.
- **Financial Inclusion Gaps:** While the Jan Dhan Yojana has expanded bank access, credit uptake remains minimal due to lack of collateral. KSCP should collaborate with agri-fintechs and microfinance institutions to enable easier loan access (Kejriwal & Bharadwaj, 2025).
- **Reaching Marginalized Areas:** The first phase of KSCP covered only 12 states. Expanding to remote and tribal regions requires mobile training units, satellite education and community radio programming to enhance outreach (The Times of India, 2024).

Addressing these gaps can amplify KSCP's scalability and make it a national model for gender-responsive, climate-resilient agriculture.

Conclusion

The Krishi Sakhi Convergence Programme stands as a paradigm for women-driven agrarian transformation. By empowering women with knowledge, resources and leadership skills, KSCP not only enhances agricultural productivity but also strengthens rural communities and contributes to sustainable development goals. Its innovative approach to combining scientific advancements with traditional wisdom creates a replicable model for inclusive agricultural development across India and beyond.

Reference

Cassen, R. (2004). The future of India's economic growth: The natural resources and environmental constraints. *Futures*, *36*(2), 197–204. https://doi.org/10.1016/S0016-3287(03)00250-7

Das, M. (2024). Socio - cultural perspective of gender inequality: a plan for national development by women empowerment. *International Journal of Advanced Research*. https://doi.org/10.21474/ijar01/19111

Gupta, N., Pradhan, S., Jain, A., & Patel, N. (2021). *Sustainable agriculture in India 2021: What we know and how to scale up*. Council on Energy, Environment and Water (CEEW). https://www.ceew.in/publications/sustainable-agriculture-india

Kejriwal, A., & Bharadwaj, M. (2025, February 12). *Scaling digital services to spur financial inclusion of rural women*. Accion Advisory. https://www.accion.org/scaling-digital-services-to-spur-financial-inclusion-of-rural-women

Khulbe, S., & Joshi, P. chandra. (2024). Socio-economic Empowerment of Women in Rural Area of Udham Singh Nagar District (With Special Reference to Kiccha Block). *International Journal for Multidisciplinary Research*. https://doi.org/10.36948/ijfmr.2024.v06i02.17340

Ministry of Rural Development. (2024, July 12). *DAY-NRLM mobilised over 10.04 crore women into over 90.76 lakh SHGs: Charanjit Singh*. Economic Times Government. https://government.economictimes.indiatimes.com/news/economy/day-nrlm-mobilised-over-10-04-crore-women-into-90-76-lakh-self-help-groups/111689012

Pradhan, S., Raksha, G. S., & Akhil, P. M. S. (2024). Role of Women in Food and Agricultural Development. *Advances in Environmental Engineering and Green Technologies Book Series*, 130–148.

https://doi.org/10.4018/979-8-3693-3037-1.ch008

Press Information Bureau. (2024, June 18). *Krishi Sakhi: Women as para-extension workers*. Ministry of Agriculture & Farmers Welfare, Government of India. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2026015

Rasheed, A., Mwalupaso, G. E., Abbas, Q., Tian, X., & Waseem, R. (2020). Women Participation: A Productivity Strategy in Rice Production. *Sustainability*, *12*(7), 2870. https://doi.org/10.3390/SU12072870

Statetimes. (2025, June 9). *Women empowerment: Role of Krishi Sakhis in agriculture development* (P. Parihar, Ed.). https://statetimes.in/women-empowerment-role-of-krishi-sakhis-in-agriculture-development/

The Times of India. (2024, June 19). *Krishi Sakhi plan enabling rural women earn ₹60K per year*. Varanasi Edition. https://timesofindia.indiatimes.com/city/varanasi/krishi-sakhi-plan-enabling-rural-women-earn-60k-per-yr

United Nations. (2015). *Transforming our world: The 2030 agenda for sustainable development.* United Nations.https://sustainabledevelopment.un.org/post2015/transformingourworld/publication

Women's Earth Alliance. (n.d.). *Women in agriculture: Facts and data*. https://womensearthalliance.org/programs/women-food-climate-change-training/

Sip Your Way to Better Health: The Remarkable Benefits of Loquat Leaf Tea

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In a world turning increasingly to nature for answers, loquat leaf tea is re-emerging not as a relic of folk medicine, but as a powerful, science-backed ally in modern wellness. Sourced from the resilient *Eriobotrya japonica* tree, this bitter, golden infusion is rich in bioactive compounds particularly flavonoids and triterpenoids that act on the body's most critical pathways to reduce inflammation, neutralize oxidative stress, regulate blood sugar, and support immune balance. This article delves into the journey of the loquat leaf from its botanical roots in East Asia to its rise as a promising functional beverage. We explore its diverse therapeutic effects, innovations in processing, and its expanding role in health-focused foods from herbal teas to fortified noodles and cookies. Clinical and preclinical studies are reviewed to validate traditional claims and uncover the mechanisms behind its metabolic, respiratory, dermatological, and anti-aging benefits. Yet, for all its potential, loquat leaf tea stands on the threshold of greater recognition. With robust research and standardized practices, it could soon redefine how we sip our way to better health merging ancient wisdom with cutting-edge science in a single, restorative cup.

***Keywords**:* Loquat leaf tea, Functional beverages, Natural anti-inflammatory, Herbal antioxidants, Plant-based wellness, metabolic Health

1.1. Introduction:

The Tea with a Healing Legacy

What if your daily brew could fight inflammation, diabetes and more? A simple tea with the power to ignite cellular defenses, quell inflammation and support metabolic resilience, all while offering a soothing moment of calm. From its origin in ancient China to its rising status as a functional beverage today, this herbal infusion is poised to captivate both traditional seekers and health minded innovators. *Eriobotrya japonica* more commonly known as loquat, a evergreen shrub member belongs to the *Rosaceae* family it bears leathery, serrated leaves and fragrant white flowers that bloom in late autumn or early winter, giving way to succulent orange fruit in spring (Dhiman *et al.*, 2021*).*

Figure 1. Loquat leaf tea with loquat freshly harvested and roasted leaf

Loquat originated in the misty highlands of south-central China and has been cultivated for over 2,000 years. It is referenced in classical Chinese texts like the *Compendium of Materia Medica*, which outlined its healing properties for respiratory and gastrointestinal ailments. It later spread to Japan during the Tang dynasty and became widely embedded in Japanese pharmacognosy. By the 18th century, loquat was introduced to Europe through colonial botanical expeditions and gradually disseminated across the Mediterranean and subtropical regions worldwide (Elimasni and Nasution, 2021). Today, loquat is grown in over 30 countries, including China, Japan, Spain, India, Turkey, the United States, Brazil, and Pakistan. China leads with an estimated 170,000 hectares under cultivation and over 1 million metric tons of annual production. Spain, another key player, grows approximately 40,000 tons annually, exporting the majority to European markets (Jiang *et al.*,2022).

1.2. Meet the Loquat Leaf: Nature's Pharmacy

Eriobotrya japonica is a slow-growing, evergreen tree with a spreading canopy and a height that ranges from 5 to 10 meters under natural conditions. Its leaves are among its most distinctive features large (12–25 cm long), lanceolate to oblong-lanceolate, dark green on the surface, and covered with soft white to rusty hairs on the underside (Kunkel, G. 2012). The thick cuticle and prominent parallel venation suggest an evolutionary adaptation to moderate drought, high solar radiation, and pathogen resistance. These anatomical traits not only protect the tree in subtropical environments but also serve as storage reservoirs for bioactive compounds, many of which are concentrated in the leaf's epidermal and subepidermal tissues (Elimasni and Nasution, 2021).

Figure 2. Loquat leaves before harvest

Figure 3. Loquat fruit and leaves prior harvest

1.3. Phytochemical Profile: A Synergistic Powerhouse

Loquat leaves are rich in a variety of phytochemicals, particularly flavonoids such as quercetin and kaempferol, and triterpenoids like ursolic and oleanolic acid. These compounds are primarily responsible for the leaf's antioxidant, anti-inflammatory, and metabolic-modulating activities, and will be explored further in subsequent sections (Nawrot- Hadzik *et al.*, 2017).

1.4. Science in a Cup: How the Tea Is Made Matters

Every sip of loquat leaf tea begins not in your teacup, but amid the rustling leaves of an orchard. Understanding its journey, from harvest to infusion, reveals how each step fine-tunes its health potential and sensory appeal.

- **Harvesting the Leaves**

In spring or early summer, when the tree bursts with tender foliage, growers hand-select mature, dark-green leaves that are robust yet free of disease or insect damage . This timing ensures peak levels of flavonoids, phenolic acids, and triterpenoids, which naturally decline as leaves age (Özcan *et al.*, 2019).

- **Cleaning & Deburring**

After harvest, the leaves are thoroughly rinsed under cool water to remove residue and potential contaminants . A key detail,using a soft brush or cloth to gently scrape off the fine hairs on the underside,ensures a smoother mouthfeel in the final brew.

- **Withering & Drying**

Clean leaves are then air-dried in shade or mild airflow, or lightly oven-dried, until they become pliable. This withering stage reduces moisture (~30–50%), subtly activates oxidative enzymes, and develops aromatic compounds (Telaumbanua *et al.*, 2021).

- **Roasting**

Next comes a crucial leap in bioactivity: pan-roasting or dry-roasting at approximately 300–350 °C for 20–30 minutes. This "kill-green" step halts enzymatic oxidation, initiates Maillard-type reactions, and transforms existing phytochemicals into new, more powerful phenolics, boosting antioxidant and anti-inflammatory potency (Fombang *et al.*, 2020).

Figure 4: Loquat tea with roasted leaves

- **Milling & Shaping**

Post-roast, leaves are chopped or crimped, sometimes kneaded to encourage even drying and improve flavor extraction. This also creates more surface area for water to penetrate during brewing.

- **Brewing the Infusion**

To brew, add approximately 4–7 fresh leaves (or 1–2 tsp dried) to 500 ml of water, bring to a boil, then simmer for 10 minutes, cover, and steep for another 10 minutes. For roasted leaves, brew at 80–90 °C for 30–45 minutes to extract phenolics without breaking them down (Chen, 2018).

- **Reboil & Serve**

After the first steep, the same leaves can be reboiled in fresh water,yielding a gentler, second brew. Strain carefully to avoid leftover hairs, and enjoy hot or chilled. Optional additions like honey, citrus peel, or gingersnap spices (turmeric, cloves) can enhance the flavor and health benefits (Gan and Ting, 2017).

1.5. Health benefits

(a) Fighting Oxidative Stress: Loquat Leaf's Antioxidant Edge

In a world plagued by chronic inflammation and degenerative diseases, antioxidants serve as our frontline cellular guardians. Among dietary antioxidants, phenolics, flavonoids, carotenoids, and vitamins play a pivotal role in neutralizing free radicals, restoring redox balance, and activating protective genes particularly via the Nrf2 pathway to prevent oxidative damage and inflammation-related pathologies (Ibrahim, 2021; Khadiga et al., 2021). Loquat leaf tea,especially when roasted,exemplifies this principle with remarkable precision. A study by Khine Zar et al. (2013) demonstrated that roasted loquat tea extract (LTE) exhibited superior radical-scavenging capacity over fresh-leaf extract in both DPPH and reactive oxygen species (ROS) assays. Specifically, at 50 µg/mL, LTE scavenged 69.3% of DPPH radicals, substantially outperforming fresh-leaf preparations, and certain fractions reached up to 75% scavenging,an indicator of potent bioefficacy.

(b) Anti-Inflammatory Power: Cellular Calm in Every Sip

Inflammation is driven by key molecular players like COX-2 and PGE_2, which trigger pain, swelling, and tissue damage. Under stress or injury, COX-2 rapidly increases, converting arachidonic acid into pro-inflammatory compounds chief among them, PGE_2. This molecule heightens sensitivity, causes fever, and fuels chronic inflammatory conditions such as arthritis, IBD, and asthma (Luan et al., 2022). ThesStudies show that roasted loquat leaf tea extract (LTE) significantly reduces both COX-2 expression and PGE_2 production in LPS-activated macrophages, a standard inflammation model (Khine Zar et al., 2013). These effects are largely attributed to its flavonoids and triterpenoids, which effectively suppress the COX-2/PGE_2 pathway, offering a natural and targeted anti-inflammatory action.

(c) Metabolic Wellness: Managing Blood Sugar and Lipids

Among the most active ingredients in loquat leaves are ursolic acid and chlorogenic acid,both studied for their ability to improve the way our body handles sugar and fat. Ursolic acid, a plant-based triterpene, helps lower blood glucose by making cells more responsive to insulin. It activates a key energy-sensing enzyme called AMPK, which promotes sugar uptake and fat burning while reducing inflammation and oxidative stress (Wu et al., 2021; Zhang et al., 2022). Chlorogenic acid, a natural phenolic compound, slows down carbohydrate digestion by blocking enzymes that break down starch. It also helps reduce blood sugar spikes after meals and improves cholesterol levels, all while enhancing liver and antioxidant function (Ong et al., 2013; Tokuchi et al., 2022).

(d) Scientific Support from Animal Studies

Multiple lab studies on diabetic animal models have shown that loquat leaf extracts can reduce high blood sugar and harmful fats. For example: In a Moroccan study, diabetic mice given loquat leaf tea showed significant drops in blood glucose and cholesterol levels, comparable to standard drugs like metformin (Benali et al., 2022). Other research found that loquat leaf compounds helped repair insulin pathways, lower inflammation, and even improve gut health boosting helpful bacteria and reducing harmful ones (Wu et al., 2021). With anti-diabetic and cholesterol-lowering effects, it supports better blood sugar control, reduces fat accumulation, and protects the organs affected by metabolic stress. While most studies are in animals, the results are promising and reflect what has been practiced in folk medicine for centuries.

(e) Immunity and Respiratory Relief

For generations, loquat leaf tea has been a go-to remedy in many Asian households, especially during cold seasons. Its warm, slightly bitter brew has traditionally been used to soothe sore throats, loosen phlegm, and ease the breathlessness of asthma or seasonal allergies. But this isn't just folklore, modern science is beginning to explain what ancient healers have long understood. Loquat leaves contain a unique mix of natural compounds, that have been shown to reduce inflammation in the lungs and support immune balance. Research on animal models with asthma and bronchitis has found that loquat extracts can calm irritated airways, reduce mucus build-up, and lower key inflammatory signals like TNF-alpha and IL-6, the very messengers that trigger coughing, swelling, and congestion (Liu et al., 2023; Hyun et al., 2022).

(f) Beauty and Longevity: Anticancer, Anti-aging, and Skin Health

The therapeutic scope of loquat leaf tea extends beyond metabolic and immune health, encompassing significant potential in the domains of oncological protection, anti-aging, and dermal wellness. Its power is kaempferol, which regulate key cellular pathways such as NF-κB and MAPK—both involved in inflammation, tumor growth, and cellular aging (Luan et al., 2022; Zhao, 2024).

By modulating these pathways, loquat leaf compounds help prevent abnormal cell growth, reduce oxidative stress, and protect DNA from damage. Their antimutagenic and cytoprotective effects support longevity and have attracted growing interest in the cosmeceutical and nutraceutical industries. Today, loquat extracts are being used in skincare products to enhance elasticity, combat photoaging, and boost dermal repair offering a natural, science-backed approach to beauty and cellular health.

(g) Safe Sipping: Toxicity, Side Effects, and Best Practices

While loquat leaf tea offers a broad spectrum of health-promoting benefits, it is essential to approach its consumption with informed caution to ensure safety and efficacy. As with many botanical products, dosage, preparation, and part of the plant used are critical determinants of both benefit and risk.

1.6. Toxicological Assessments and Safe Dosage

Toxicological studies conducted on rodents have reported a median lethal dose (LD_{50}) exceeding 5,000 mg/kg, indicating a wide margin of safety (Mokhtari et al., 2022). Although clinical trials in humans remain limited, traditional medicine practices and contemporary herbal guidelines suggest a daily intake of 1–2 teaspoons of dried mature leaves, infused in hot water once or twice daily. This approximates to a safe human dosage of 1–2 mg/kg/day. Mild gastrointestinal disturbances such as nausea or diarrhea may occur with excessive consumption. In rare cases, significantly high intake (e.g., >2 liters/day for extended periods) has been linked to toxic myopathy. These risks are mitigated through proper roasting or boiling, and by excluding seeds from preparations. Pregnant or lactating individuals, as well as those on antidiabetic or antihypertensive medications, are advised to consult a healthcare provider prior to use.

1.7. Leaf to Lifestyle: Future Directions for Loquat Leaf Tea

Individuals who are pregnant, breastfeeding, or taking hypoglycemic or antihypertensive medications should consult a healthcare professional prior to use due to potential interactions with metabolic pathways. Additionally, seed consumption should be strictly avoided, as seeds contain higher concentrations of cyanogenic compounds.

As scientific interest in botanical therapeutics continues to expand, loquat leaf tea is poised to evolve from a traditional remedy into a versatile functional ingredient within modern food and health systems. Beyond its use as an herbal infusion, emerging research supports its integration into value-added products such as functional cookies, tofu, and noodles, offering both health benefits and commercial viability. Technological innovations in processing, including spray-drying, microencapsulation, and controlled fermentation, have opened new pathways to preserve and enhance the stability, bioavailability, and sensory appeal of loquat-derived compounds. These methods not only extend shelf life but also ensure consistent phytochemical delivery in functional formulations. Despite encouraging in vitro and animal model findings, a key limitation remains: the lack of well-designed human clinical trials. Although current evidence is promising, especially in preclinical models, the absence of standardized human clinical trials remains a limitation. Establishing dosing guidelines and confirming long-term efficacy through well-structured trials will be crucial for the widespread acceptance of loquat leaf tea as a validated functional food. As global demand for natural, plant-based wellness solutions rises, loquat leaf tea holds considerable promise, not only as a time-honored beverage. With its rich therapeutic potential, adaptable processing, and growing consumer appeal, loquat leaf stands at the intersection of tradition and innovation, ready to redefine the future of healthful living.

References

1. Benali, M., El Messaoudi, L., Talbaoui, A., et al. (2022). Nutritional, phenolic composition, antidiabetic and antihyperlipidemic properties, and safety profile of loquat (*Eriobotrya japonica*) leaf aqueous extract in HFG-diet mice. *Phytotherapy Research*.
2. Chen, S.-Y., Huang, P.-H., Shih, M.-K., Wu, C.-C., Hsieh, C.-W., Chen, M.-H., Hsieh, S.-L., & Hou, C.-Y. (2023). *Functional evaluation of loquat (Eriobotrya japonica Lindl.) flower water extracts and its potential use in tea. Journal of Food Processing and Preservation*, Article ID 1188178. \
3. Dhiman, A., Suhag, R., Thakur, D., Gupta, V., & Prabhakar, P. K. (2021). *Current status of loquat (Eriobotrya japonica Lindl.): Bioactive functions, preservation*

4. *approaches, and processed products*. *Food Reviews International*, 1–22.
5. Gilman, E. F., Watson, D. G., et al. (2022). *Eriobotrya japonica: Loquat* (UF/IFAS Extension). University of Florida.
6. Grosso, G. (2018). Dietary antioxidants and prevention of non-communicable diseases. *Antioxidants (Basel)*, 7(7), 94.
7. Hyun, M. K., Kim, D. H., Park, C. H., Lee, H. S., & Kim, J. Y. (2022). Protective mechanisms of loquat leaf extract and ursolic acid against diabetic pro-inflammation. *Journal of Molecular Medicine*, *100*(10), 1455–1464
8. Ibrahim, K. S. (2021). Efficacy of dietary antioxidants in disease prevention. In V. Rajendran & P. Kumar (Eds.), *Oxidative Stress and Natural Antioxidants* (pp. 209–230). Bentham Science Publishers.
9. Jiang, Y., Polat, A. A., & Lin, S. (2022). Origin, History and Production. In *Loquat: Botany, Production and Uses* (pp. 1-20). GB: CABI.
10. Khadiga, S. I. (2021). Efficacy of dietary antioxidants in diseases prevention. In Oxidative Stress and Natural Antioxidants.
11. Khine Zar, P. P., Sakao, K., Hashimoto, F., Morishita, A., Fujii, M., Wada, K., & Hou, D.-X. (2013). *Antioxidant and anti-inflammatory activities of loquat (Eriobotrya japonica) tea. Functional Foods in Health and Disease*, 3(11), 447–461.
12. Kumar, V., Gupta, P., & Kumar, M. (2024). *Loquat and its phytochemical potential: A promising application in food technology*. *eFood*, 5, e158.
13. Kunkel, G. (2012). *Flowering trees in subtropical gardens*. Springer Science & Business Media
14. Liu, Y., Wang, X., Chen, Y., & Zheng, J. (2022). Effects of roasting on flavonoid glycosides in tea leaves. *Food Chemistry*, 374, 131593.
15. Luan, M., Wang, H., Wang, J., Tan, J., Li, X., & Zhang, Y. (2022). Advances in anti-inflammatory activity, mechanism, and therapeutic application of ursolic acid. *Mini Reviews in Medicinal Chemistry*, *22*(3), 422–436.
16. Mendoza, J. D., Wada, K., & Hou, D.-X. (2021). Enhancing antioxidant power through controlled roasting: A comparative study. *Journal of Agricultural and Food Chemistry*, 69(22), 6354–6363.
17. Ong, K. W., Hsu, A., & Tan, B. K.-H. (2013). Anti-diabetic and anti-lipidemic effects of chlorogenic acid mediated by AMPK activation. *Biochemical Pharmacology*, *85*(9), 1341–1351.
18. Özçağıran, F. (2005). Leaf morphology of loquat genotypes. *Genetic Resources and Crop Evolution*.
19. Tan, H., Zhao, C, (2019). Ursolic acid… inhibits osteoclast differentiation. *Journal of Agricultural and Food Chemistry*, 67(12), 3333–3340
20. Terao, J. (2023). Revisiting carotenoids as dietary antioxidants for human health and disease prevention. *Food & Function*, 14, 7799–7824.
21. Tokuchi, M., Nakamura, T., & Yamazaki, F. (2022). Chlorogenic acid improves glucose tolerance, lipid metabolism, inflammation and gut microbiota composition in db/db mice. *Journal of Nutritional Biochemistry, 103*, 108–116.
22. Wu, R., Chen, J., & Li, L. (2021). Total sesquiterpene glycosides from loquat leaves ameliorate insulin resistance by modulating IRS-1/GLUT4, TRPV1, and SIRT6/Nrf2 signaling. *Food & Function, 12*, 7890–7902.
23. Zhang, H., Wang, L., Li, J. (2022). Protective mechanisms of loquat leaf extract and ursolic acid against diabetic pro-inflammation via LKB1–AMPK–FOXO3 pathway. *Molecular and Cellular Endocrinology, 561*, 111–128.
24. Zhao, X. Y. (2024). *Comprehensive review of bioactive compounds in loquat and their pharmacological mechanisms*. *Medicinal Plant Research*, 14(4), 196–209.

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Lactic Acid Bacteria: Helpers in Unexpected Places

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Lactic acid bacteria are a wide range of organisms that are significant to humans, which grow and survive at low or no oxygen in acidic environmental conditions rich in carbohydrate content. These organisms are not just present in dairy products but also undergo the process of fermentation, which helps to make fermented food and various products to enhance the shelf life, flavour, and acts as a probiotic. These are ubiquitous organisms which are present in vast areas like soil, plants, insects, flowers, fermented fish and meat, human skin and body. These organisms play an important role in food safety, improvement in plant growth and health, and are effective against pathogens since it produce certain acids and antimicrobial substances.

Introduction

Lactic acid bacteria (LAB) are a diverse group of beneficial microorganisms that are gram-positive, non-spore-bearing, and non-motile. They are generally rod-shaped or coccoid in shape. It can withstand both acidic conditions and moderate temperatures. They tend to survive in low-oxygen environments, which makes them suitable for use in fermentation processes. These are commonly found in areas rich in carbohydrates and under acidic pH conditions. This group of microorganisms typically undergoes fermentation, converting carbohydrates into lactic acid as an end product. This simple process allows them to act as a good preservative, flavor enhancer, and probiotic. From fermenting milk to dairy products to enhancing the gut microbiota, these have played a vital role in humans for centuries. However, their importance stretches far beyond this.

Habitats and Application of Lactic Acid Bacteria

Good Bacteria in Every Spoon

LAB play a crucial role in dairy products by enhancing their flavor and texture, as well as aiding in preservation. These bacteria convert milk sugar into lactic acid through a process known as lactic acid fermentation. This process lowers the pH of the milk, which helps reduce spoilage and extends the shelf life of milk and its products by creating an acidic environment that inhibits the growth of harmful microorganisms. Key types of lactic acid bacteria include *Lactobacillus* spp., *Streptococcus* spp., and *Leuconostoc* spp. In addition to improving flavor and texture, lactic acid bacteria produce various compounds that contribute unique tastes, such as buttery or tangy, to dairy products. Furthermore, these bacteria aren't exclusive to milk and its products; they can also survive in a variety of ecosystems.

Insects as Carriers

LAB commonly inhabit the digestive systems of various insects. Numerous researchers have identified multiple strains of these beneficial bacteria, which assist with food digestion and protect against pathogens by forming symbiotic relationships with insects. These bacteria efficiently metabolize food, particularly from plant-based sources, converting it into essential nutrients that support the health and vitality of insects. Furthermore, they help combat infections caused by pathogenic bacteria and fungi, ultimately improving gut health. Additionally, lactic acid bacteria enhance the quality of honey, underscoring their important role within the insect microbiome, as they share a mutual survival.

Soil and Plant Roots

LAB are found in various environments associated with plants. They inhabit the surfaces of plant leaves and stems, known as the phyllosphere; some can invade plant tissues (endosphere), while others reside in the soil surrounding plant roots (the rhizosphere). These bacteria not only occupy these areas but also release compounds that facilitate interactions, provide protection, and aid in the repair of damaged plant tissues. Additionally, they produce growth-promoting substances, such as auxins and gibberellins, which directly stimulate plant growth, enhance root development, and improve water uptake, acting as biostimulants. They also help solubilize nutrients, such as phosphorus, making them more available for plant uptake, thus acting as biofertilizers.

Furthermore, LAB are attracted to specific chemical compounds and acids released by plants, helping them accumulate on the surface of the root system. Some researchers are discovering that these bacteria can play a significant role in eco-friendly agricultural practices, such as improving crop yields, enhancing nutrient uptake, promoting soil health, and controlling pests and diseases.

Tiny Residents in Flowers

LAB commonly inhabit flowers, particularly in the diverse nectar and pollen they contain, which supports a wide range of these organisms. Researchers have successfully identified and isolated LAB from several flower species, including *Convolvulus arvensis*, *Hibiscus rosa-sinensis*, and *Rosa rugosa*. These bacteria play a crucial role in maintaining the flower ecosystem and enhancing nutrient uptake. Furthermore, LAB isolated from flowers are utilized in various applications, including food fermentation, plant-based foods, and the agricultural sector.

Fermented Fish and Meats

In the traditional process of fermenting fish and meat, LAB naturally grow, helping to protect the food from spoilage organisms. This process also improves the texture, aroma, and flavor of the food. Even with dried or smoked meat, LAB aids fermentation by producing acids through acidification. LAB breaks down the proteins in the meat and fish, which supports microbial growth and releases compounds that enhance flavors, thereby increasing shelf life and acting as a natural preservative.

Living with LAB

LAB are not only found in food but also naturally inhabit the skin and the human body. They are part of the skin microbiome, which plays a defensive role against pathogenic organisms. These bacteria produce acids and peptides that can inhibit disease-causing organisms, helping to prevent autoimmune disorders associated with the skin. They are also well-known for their presence in the gut microbiota, where they play a significant role in digestion and immune function.

Conclusion

From ancient food practices to modern health-conscious trends, lactic acid bacteria have played a significant role in food, agriculture, dairy, and therapeutic applications due to their probiotic properties and antimicrobial components.

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Building Climate Resilient Agriculture for A Sustainable Future

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Introduction

Climate change is driven by a combination of natural processes and human activities. Natural factors include continental drift, volcanic eruptions, variations in Earth's tilt, and shifts in ocean currents – all of which have historically influenced global climate patterns. Human-induced (anthropogenic) factors – such as rapid urbanization, industrialization, fossil fuel combustion, deforestation, and unsustainable agricultural practices—have significantly accelerated climate change in recent centuries. By 2050, the global population is projected to reach 9 billion, necessitating a 70% increase in food production to meet demand. However, climate change poses a significant threat to agricultural productivity, with rising temperatures (expected to increase by 1.8°C to 4°C), erratic rainfall patterns, and extreme weather events such as heatwaves, storms, and flooding disrupting farming systems worldwide. Compounding the challenge, the agricultural sector itself contributes approximately 30% of global greenhouse gas (GHG) emissions, primarily through synthetic fertilizer use, low nutrient – use efficiency, enteric fermentation in livestock, and conventional rice cultivation practices. These emissions further accelerate climate change, creating a feedback loop that threatens long-term agricultural sustainability. By integrating mitigation and adaptation strategies, the global agricultural sector can safeguard food supplies while contributing to climate stabilization.

Climate–Resilient Agriculture

Resilience refers to a system's capacity to anticipate, withstand, adapt to, and rapidly recover from disruptive events while maintaining core functionality. Climate – resilient agriculture takes this concept further by enabling farming systems to not just bounce back from climate shocks, but to evolve and improve. Rather than simply restoring previous conditions, it transforms agricultural practices to become more robust and sustainable in the face of future challenges. This forward looking approach ensures long term productivity while enhancing the ecosystem's capacity to cope with changing climatic conditions.

The Climate-resilient agriculture (CRA) includes 3 phases – Recognition phase, curing phase, sustaining phase.

1. **Recognition phase:**

- Long-term threats – Ground water depletion, crop burning, pattern change in rainfall, soil organic carbon degradation, atmosphere and groundwater pollution, urbanization, industrialization, etc.
- Short-term threats – Flood, drought (early-season, mid-season and terminal drought), frost, heat/cold wave, cyclone, hail-storm, insect pest attack etc.

2. Curing Phase

- **Adaptation –** "Adjustment in ecological, social, or economic system in response to actual or expected stimuli and their effects or impact. The term refers to change in process practice and structure to moderate potential damages or to benefit from opportunities associated with climate change" (IPCC. 2001).
- **Mitigation –** Using new technologies and renewable energies to making older equipment more energy efficient or changing management practices or consumer behavior.

2.1. Adaptation to Climate Change

A. Weather based agro-advisories – Weather stations at KVK and mini-weather observatories in villages are set up to record real-time data on rainfall, temperature, humidity, and wind speed. The agro advisory is then displayed in local languages as a wallpaper at Panchayat buildings, schools, or other convenient locations accessible to all farmers. Mobile phones are used to send personalized weather updates to farmers, making them increasingly popular among rural users

B. Crop and variety selection – Choosing a climate-smart crop variety is the best adaptation strategy, as crops with flexible sowing windows can be planted over a broader range of dates. Crops should be chosen based on weather forecasts and research. Basmati rice, tea, and coffee are sensitive to rising temperatures, so they should be grown in areas where the climate supports good quality.

C. Efficient cropping system – Cropping system must suit the location, support soil health, control weeds, and minimize pest outbreaks. Mixed cropping, intercropping, and relay cropping reduce climate risks, ensuring farmers can harvest at least one crop during adverse conditions. Pigeonpea, whether as a main crop or intercrop, performed well, especially in sorghum, cotton, and pearl millet-based cropping systems. Legumes in a cropping system - adding soil cover and biological nitrogen.

D. Water harvesting – India, with a geographical area of 3.29 million km² supports over 18% of the world's population but only 4.2% of it is freshwater according to the World Bank. The rise in temperature by 1°C will increase the crop water demand by 2%. Climate change significantly affects sea levels, leading to potential changes in the salinity of both surface and groundwater in coastal areas. Increased precipitation leads to runoff, while rising temperatures increase evapotranspiration. In dry and dryland farming areas during the rainy season, rainwater harvesting systems like water tanks, dug wells, percolation tanks, and farm ponds are used to collect rainwater. Similarly, micro-catchments, small farm reservoirs, rooftop systems, water spreaders, inter-row harvesting, and on-farm systems (small pits, runoff basins, strips, etc.) are also preferred.

E. Balanced fertilization – Providing right amount of all nutrients throughout a crop's growth for healthy growth, better yield, and good quality. Nitrogen is needed for protein synthesis, and the plant requires the right amount of energy and enzymes, which come from phosphorus and potassium. Using fertilizers in the right amounts helps reduce nutrient loss. Balanced fertilization supports healthy plant growth, uses nutrients efficiently, and has less impact on the environment.

F. Custom hiring of farm machinery – Community nurseries and shared farm machinery help reduce environmental pressure by lowering the need for individual cultivation. Community-managed custom hiring centers are set up in each village to provide access to farm machinery for timely planting. This is an important solution for dealing with changing climates, such as delayed monsoons and insufficient rain, which may require replanting crops.

G. Contingency planning – It involves preparing alternative crops and cultivators based on the rainfall and soil resources of a specific location. In rain-fed areas, early sowing of crops with the onset of the monsoon is the best practice for achieving the highest yield. Generally, practices like resowing, thinning crops, removing alternate crops, applying 2% urea or KNO3 or DAP, and growing storm-resistant crops (such as ginger, pineapple, etc.) are effective contingency cultivation methods to tackle climate change.

2.2. Mitigation to Climate Change

A. Reduction of food losses and waste – We usually focus on increasing food production, but reducing food loss can improve resource efficiency, easing the pressure on farmers and food production industries. At home, one of the best ways to reduce food waste is by planning meals in advance, using up perishable items first, and freezing any extra garden vegetables. You can process or dehydrate surplus or damaged fruits, vegetables, and meats. Composting kitchen waste also helps improve soil health.

B. Improved crop management practices – Well-managed farmland offers many opportunities to promote sustainable crop production. In India, rice is mainly grown through transplanting, which harms groundwater resources. Intermittent irrigation reduces CH_4 production by 40% but increases N_2O-N emissions by 6%. This happens because more water-filled pores and lower bulk density in the surface reduce oxygen diffusion into the soil, although the total carbon flux decreases with this method. In rice fields, CH_4 emissions peak during the tillering to reproductive stage, where 90% of the CH_4 is released through aerenchyma tissue. To reduce CH_4 emissions, systems like direct seeded rice (DSR) and alternate wetting and drying (AWD) can be used. DSR can reduce CH_4 emissions by about 80-90%, while AWD can reduce them by 30-40%. Along with this DSR reduces 30-40% water with an advantage of early sowing.

C. Recarbonization of soils – Managing soil organic carbon is essential for building soil resilience to climate change. Increasing soil carbon can improve water infiltration, fertility, nutrient cycling, reduce erosion, minimize compaction, enhance water quality, and overall improve environmental quality. Enhancing carbon sequestration can be achieved through best management practices such as residue management, using permanent plant cover instead of fallow periods, incorporating legumes in crop rotations, and adopting agroforestry. Retention of crop residue without burning lead to addition of carbon to the soil, 1 tonne of rice residue burning emit 1515 kg CO_2, 0.4kg SO_2, 2.5kg CH_4, 92kg CO, 3.83 kg NOx and non methane volatile organic compound.

D. No-Till system – Zero or no-tillage improves soil physical properties, reduces greenhouse gas emissions, and saves labor and fuel costs while minimizing soil erosion and preserving nutrients, whereas conventional tillage results in 6–31% higher net global warming potential compared to no-till, which also enhances soil organic carbon sequestration and saves 35 liters of diesel per hectare (avoiding the emission of 2.67 kg CO_2 per liter) during land preparation.

E. Site specific nutrient management – Agriculture contributes 70-90% of nitrous oxide (N2O) emissions, mostly from N fertilizer. SSNM, which involves applying the right amount, source, rate, time, and method of nutrients, includes both prescriptive and corrective approaches, prescriptive by adding nutrients based on soil tests, crop needs, and climate conditions, and corrective by using tools like chlorophyll meters and leaf colour charts, while also reducing N_2O emissions through optimized nitrogen application.

F. Integrated farming system (IFS) – It offers great potential for farmers to grow different crops on the same land and use resources sustainably. It is less risky, improving resource efficiency, reduces the dependence of output. It results in proper recycling on by products, crop residue, weed, an all-other farm wastes combined with conservation of farm resource have been found to reduce chemical load in the form of inorganic fertilizer by 36%.

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3. Sustaining Phase:

- The system should sustain their adaptive mechanisms over a long time.
- CRA with these mechanisms, building itself in such a way that it can break through any hurdle that would come its way.
- The effect of climate change is very frequent, to combat this situation CRA should always be prepared with best adaptive and mitigative mechanisms.
- Climate resilient agriculture not only to be implemented, should be sustained or maintained over the time being through different village level awareness program.
- Government plays an important role through different schemes and subsidies.
- Technology demonstrations under the National Initiative on Climate Resilient Agriculture are currently in operation in 100 vulnerable districts.

Conclusion

Climate-resilient agriculture is essential for ensuring food security in an era of climate uncertainty. The future of food depends on adapting to climate change now. From drought-resistant crops to precision irrigation, solutions exist—but they require investment, education, and policy support. By working together, farmers, scientists, and governments can build an agriculture system that feeds the world, no matter what the climate brings.

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Bioactive Compounds in Mushrooms and Their Health Implications

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Mushrooms have been valued for their culinary and medicinal properties for thousands of years. Traditionally used in various cultures, especially in Asia, mushrooms are now recognized worldwide for their potential health benefits. Their medicinal value is attributed to a rich profile of bioactive compounds, including polysaccharides, antioxidants, vitamins, and minerals.

Key Medicinal Benefits of Mushrooms

1. Immune System Support
Many mushrooms contain beta-glucans and polysaccharides that enhance the immune response. These compounds stimulate the activity of white blood cells, improving the body's ability to fight infections and possibly reducing the risk of certain diseases.

2. Anti-Cancer Properties
Research has indicated that certain mushrooms, such as Reishi, Shiitake, and Maitake, possess anti-tumor properties. They may inhibit cancer cell growth, induce apoptosis (programmed cell death), and improve the efficacy of conventional treatments.

3. Antioxidant Activity
Mushrooms are rich in antioxidants like selenium, ergothioneine, and polyphenols, which help neutralize free radicals. This reduces oxidative stress, potentially lowering the risk of chronic diseases such as cardiovascular disease and neurodegenerative disorders.

4. Anti-Inflammatory Effects
Compounds found in mushrooms can modulate inflammatory responses, which is beneficial in managing conditions like arthritis and other inflammatory diseases.

5. Antiviral and Antimicrobial Properties
Certain mushroom extracts exhibit antimicrobial activity against bacteria, viruses, and fungi, supporting their use in infection control.

6. Cardiovascular Health
Some mushrooms, notably Shiitake and Oyster, contain compounds that can help lower cholesterol levels and improve circulation, contributing to heart health.

7. Blood Sugar Regulation
Studies suggest that some medicinal mushrooms may help regulate blood sugar levels, making them potentially beneficial for diabetics.

Common Medicinal Mushrooms

Reishi (*Ganoderma lucidum*): Known as the "Mushroom of Immortality," it is revered for its immune-enhancing and anti-cancer properties.

Shiitake (*Lentinula edodes*): Contains lentinan, which boosts immunity and has anti-tumor effects.

Maitake (*Grifola frondosa*): Supports immune function and may aid in blood sugar regulation.

Cordyceps: Used to improve stamina, energy, and respiratory health.

Lion's Mane (*Hericium erinaceus*): Promotes nerve regeneration and cognitive health.

Usage and Precautions

While medicinal mushrooms offer numerous health benefits, they should be used responsibly. It's advisable to consult healthcare professionals before incorporating them into treatment regimens, especially for individuals with existing health conditions or those on medication. Proper identification and sourcing from reputable suppliers are crucial to avoid adverse effects.

Conclusion

Mushrooms possess significant medicinal properties that can complement conventional therapies and contribute to overall health. Ongoing research continues to uncover their potential, making them valuable natural resources in the pursuit of health and disease prevention.

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Edible Insects: A Sustainable Protein Revolution – Scopes, Challenges, and the Path Forward

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With the human population of the world racing ahead and more than 9.7 billion people expected by 2050, edible insects are becoming a very nutritious as well as environmentally friendly source of protein. Full of protein, essential amino acids, vitamins, minerals and healthy fats, insects consume considerably less land, water and emit far less greenhouse gases compared to conventional livestock. Although there is already a great number of insects as a staple food in Asian, African, and Latin American food, the western world has bought into the market insect-made snacks, protein bars, and drinks. Conquering such obstacles as cultural resistance, lack of clear regulations and production challenges, as well as allergy-related issues will be essential. Insect protein has the potential to create a healthier, more sustainable global food future with innovation, education and favorable policies.

Keywords*:* edible insects, sustainable protein, nutrition, food security, environmental sustainability, consumer reception.

Introduction: The Future of Protein

By 2050, the world population is projected to exceed 9.7 billion, and it is possible that the protein demand will increase almost twice as much as now, and current food strategies will not be able to cope with it. Western sources of protein meat, poultry, fish and dairy are demanding of resources and burdensome to the environment. FAO (2013) states that farm livestock production alone emits close to one-quarter of the greenhouse gases, deforests lands, and uses colossal quantities of water, which are major challenges when urbanization and climate change have to be coped with. Edible insects have therefore been a very attractive alternative that is sustainable in this setting. Insects are already eaten by more than 2 billion individuals around the globe who highly rely on insects as a source of good protein, and essential and non-essential amino acids, iron, and zinc among other essential nutrients (Van Huis, et al., 2013). They need little land and water and feed and can be sustained on organic wastes, which helps to reduce wastes and convert valuable protein output. In addition, insects are quite versatile and, thus, can be easily added to different foods. Nevertheless, it is not freely accepted due to cultural prejudice and the lack of well-developed rules, in particular, in Western countries. These barriers must be addressed to have a transformative impact on global food security and food sustainability that insects can play. With the world becoming more environmentally challenged and nutritionally challenged, the introduction of edible insects into the mass diets might not only remain an option, but a must.

The Nutritional Value of Insect Protein

Insects hold a nutritional richness being high-quality protein, essential amino acids, and micronutrients, which can in many cases exceed conventional sources of proteins in both density and range (Hawkey *et al.*, 2021). Their peculiar nutritional content promises to be an effective way of correcting world malnutrition and advocating sustainable nutrition (Table 1).

Edible insects, with their remarkable nutritional and environmental advantages, are poised to play a critical role in addressing global food security and creating sustainable protein solutions (Abbasi, 2025).

Table 1: Nutritional Profile and Health Benefits of Edible Insects

Nutritional Aspect	Key Details	Health Benefits	References
High Protein Content	60–70% protein by dry weight (higher than beef at 25–30%)	Supports muscle growth, tissue repair, metabolic health, and overall development	Hermans *et al.*, 2021
Complete Essential Amino Acids	Rich in lysine, methionine, and tryptophan	Lysine: aids collagen formation and calcium absorption; Methionine: supports liver function and detoxification; Tryptophan: regulates mood and sleep	Wu, 2020
Micronutrient Richness	High in B vitamins (especially B12, riboflavin) and minerals (iron, zinc, magnesium)	B12: supports nerve function and red blood cell formation; Iron: reduces risk of anaemia; Zinc: boosts immunity and wound healing; Magnesium: supports bone and muscle function	Mwangi *et al.*, 2018
Healthy Fats	Contains both omega-3 and omega-6 fatty acids	Promotes cardiovascular health, brain function, and reduces inflammation	Nowakowski *et al.*, 2022
Dietary Fibre (Chitin)	Contains chitin from exoskeletons (a prebiotic fiber)	Supports gut health by promoting beneficial gut microbiota	Kipkoech, 2023
High Caloric Density	Dense calorie source in small quantities	Useful for addressing energy deficiencies in malnourished populations	Tao & Li, 2018
Low Allergenicity (with Caution)	Highly digestible for most, but potential cross-reactivity with shellfish allergies due to chitin	Suitable for many diets, but requires careful labeling for allergic individuals	Ribeiro et al., 2018; de Gier & Verhoeckx, 2018
Versatile for Fortification	Easily processed into powders and incorporated into various foods	Improves nutritional value of products like protein bars, baked goods, and snacks	Ardoin & Prinyawiwatkul, 2020

Environmental Benefits of Edible Insects

The environmental benefits that insect farming offers are considerably high and much better than that offered by conventional livestock husbandry as far as agriculture is concerned. Studies have shown that edible insects provide a sustainable option to source of proteins to humanity that is faced with the serious challenges of environmental change and lack of resources as well as waste issues (Moruzzo *et al.*, 2021; Guiné et al., 2021). In this case, we explain on main environmental advantages of edible insects.

1. Low Land Use: Insect farming uses considerably less farming space as compared to livestock farming. An example is that farming of crickets takes only a part of the land that is required to farm beef. Insect farming is also a more sustainable form of agriculture since this farming method contributes towards the protection of the forests and the promotion of biodiversity since little or no habitat needs to be converted (Van Huis & Oonicx, 2017).

2. Water Efficiency: Insects make minimal use of water compared to livestock and they consume considerably less amount of water (Noble-Nesbiti, 1990). As an example, providing identical quantities of protein to cattle takes 1% of the water required to provide the same resource using mealworms. The effective utilization of water renders insect farming an effective solution to the arid agriculture of the arid areas, thus, preserving freshwater sources (Van Huis & Oonicx, 2017).

3. Reduced Greenhouse Gas Emissions: Environmental impact of insect farming is also very little as only very few greenhouse gases are produced unlike the case of livestock (Oonincx *et al*., 2010). Unlike cattle, insects do not generate methane during digestion, and they do not require fertilizer as much as cattle so their output of nitrous oxide is less. As an example, crickets produce 80-folds fewer methane emissions compared to cattle, which reduce global warming potential.

4. Waste Reduction: The insect farming can be used as a sustainable remedy to food waste since the insects can be fed with the discarded food items. Black soldier fly larvae, as one example, have the capacity of processing 50 kilograms of waste per square meter each day and turning it into protein, chitin, and bio fertilizers (Adamtey *et al*., 2024). It also helps divert the waste that may end up in landfills and also reduce emission of toxic pollutants as a result of proper decomposition of organic waste.

5. High Feed Conversion Efficiency: Insects are very efficient in the transformation of feed into body mass (Oonincx *et al*., 2015). As an example, crickets will require 1.7 kg nuts to grow 1 kg body weight, whereas cattle needed 6 to 10 kg grain to develop a similar size. It leads to a strain on the world grain supplies which is alleviated as well as reduced environmental expenses in feed production.

6. Biodiversity Preservation and Ecosystem Services: The insect farming can contribute to the biodiversity and the ecosystem balance, as less and less land will be needed to mass breed livestock, which is directly related to the destruction of forests and habitats (Raven & Wagner, 2021). It also curbs agricultural runoffs and use of pesticides on feed crops thereby benefiting and conserving biodiversity in an ecosystem.

7. Energy Efficiency in Farming Practices Insect farming requires less energy than traditional livestock farming. The insect farming can save a lot of energy, as this requires minimal feed, water and place requirements and transport requirements are lower because the insects are produced locally (Veldkamp *et al*., 2022). This energy gain, together with its environmental output, makes the insect farming a competitor in the green agriculture.

Current Applications in Food:

1. Direct Consumption: Consumption of insects as a staple is not new in Asia, Africa and Latin America. They are used in different forms like being boiled, roasted, fried or in grilled forms. Some well-known ones are fried crickets, silkworm pupae, and mopane worms, which usually are available as street foods and in traditional dishes (Siddiqui *et al*., 2024). Even though consuming insects is not new to some places, this is new to other parts, which need to be given a space in diets by being accepted.

2. Processed Foods: Production of processed foods like protein bars, chips and crackers, and baked goods contain insect products in increasingly greater quantities, such as cricket powder. Pasta, bread, and smoothies with insect flours add nutrients and, in the health-conscious markets seeking sustainable protein alternatives, insect flours have promise to help drive pasta, bread, and smoothie consumption (Siddiqui *et al*., 2023).

3. Animal Feed: Insect protein, particularly of black soldier flies, mealworms, and crickets is becoming widely used in animal feed, and is substituting for fishmeal and soybean meal (Sajid *et al*., 2023). This assists in enhancing the wellbeing of the poultry, aquaculture and livestock growth, as well as decreasing the dependency on traditional farm crops. The environmental impacts: reduced CO_2 emissions and more efficient conversion of wastes (Abro *et al*., 2020).

4. Fortified Foods: Malnutrition especially in the developing world is being fought using insects in fortified foods. Insects contain necessary proteins, vitamins such as zinc and iron. As an example, insect-based supplies (Ready-to-Use Therapeutic Foods, RUTFs) are implemented to cure malnutrition, and insect-based snacks are getting integrated into school feeding programs, improving nutrition, and sustainability in the world (Agbemafle, 2020). Introducing insects in processed foods, animal feeds and fortified foods is a solution to nutritional deficiencies and more food security globally.

Scope of Incorporating Insects as a Protein Source:

1. Food Security:

Insect foods provide a renewable answer to food security in the world. They do not require valuable resources and space as with traditional livestock and multiply fast as well as living in most climates. Modification of insects into shelf-stable products can make the insects fit emergency food reserves and therefore contribute to food stability at the global level (Danks, 2000).

2. Functional Foods:

Insects contain high bioavailable proteins that contribute to muscle recovery, body weight control, and bone development (Rutherford *et al.*, 2025). Insects also contain chitin and chitosan that are prebiotic, and that maintain gut health. Such advantages form part of sports nutrition products such as protein powders and bars which are used by sports people or people who exercise regularly (Kipkoech, 2023).

3. Novel Culinary Trends: The insects are becoming an interesting area in the culinary art as the chefs explore their use on various gourmet menus. They are also earthy and nutty in flavor making them fit to fry, bake, use as garnish in drinks, as well as desserts. This current is useful in alleviating the phobia of insects and also in encouraging the use of insects in the contemporary food (Siddiqui, 2022).

4. Nutraceuticals Insects offer bioactive compounds with potential health benefits: The anti-inflammatory characteristics of bug proteins and fats, as well as healing properties of chitin and chitosan items, boost immunity and wound therapy (Wijesekara & Xu, 2024). Changing global trends towards natural health products are being explored in hydrolyzed insect proteins, in aspects of cardiovascular health, such as in blood pressure normalization

5. Rural Development: The insect farming holds the scope of sustainable income generation in rural and remote corners of the economically weaker sections (Abajue & Gbarakoro, 2023). It only needs minor infrastructure as it utilizes organic waste and agricultural by-products as substrates. This will help the regional economy by increasing local economies, decreasing wastes and placing people at work. The use of insects as an alternate source of protein and its use in food security, health and food innovation not only enormous potential but will contribute to rural development and sustainability (Kumar *et al.*, 2023).

Challenges in Incorporating Insect Protein:

1. Cultural Acceptance: Finally, in most of the western countries, insects are perceived as pests and this is a block to acceptability of insect based foods. The solution to this hurdle will involve education using programs to emphasize the nutrition, ecological, and gourmet value of insects. One can normalize insect protein as a sustainable food alternative by collaborating with chefs, influencer, and educators as well as featuring success stories of areas where insects are consumed traditionally (Dossey *et al.*, 2016).

2. Regulatory Frameworks: The absence of definite rules in the production of insect-based food raises insecurity among the manufacturers and the consumers. Regulatory authorities such as U.S. FDA and European EFSA will need to develop incorporated insect consumption regulatory systems that would determine food safety, quality, allergen threats, and allowable contaminants (Bento de Carvalho *et al.*, 2025). Regulation harmonization will be beneficial to market both domestically and internationally and develop consumer confidence.

3. Production Challenges: In order to produce insect protein to fulfill world demand, efficient farming systems are required. The recent agricultural practices are in need of mechanization in terms of feed, harvest and processing to cut on expenditure and improve efficiency. Development of sustainable strategies on feed will facilitate increased cost-efficiency and environmental performance through research on the use of organic wastes and by-products.

4. Allergenicity: Products of insect origin can be associated with allergenic hazards, particularly to those who are already allergic to shellfish. Allergenic proteins are the major risk to consumer safety, and their identification and control are important (Ribeiro *et al*., 2018). Enhanced labeling standards and additional studies on allergen danger will allow a reduction in health-related concerns and safe product development.

5. Consumer Awareness: The enticing of consumer confidence in insect-based products necessitates talk of origin, production, nutrition, and sustainability measures. The acceptance can be promoted through educational campaigns and marketing, and in the long run, it will be important to educate the future generations on the usefulness of insect-based foods (Puteri *et al*., 2023).

5. Economic Viability: The use of insect protein could be greatly hindered because of its high costs of production, compared to livestock farming which is cheaper in some places. The primary way of making insect protein competitive with the traditional product involves cost reduction by investing in technology, infrastructure and research, as well as effective farming and distribution systems (Madau *et al*., 2020). Industry-academia-government partnerships will play an important role in solving such issues and popularizing insect foods more widely.

Opportunities for Future Research and Development:

1. Protein Extraction Technologies: Future studies of protein recovery in insect culturing would be based on the improvement of such processes of next generation as enzyme hydrolysis, membrane filtration, and superficial fluid extraction (Jain *et al*., 2024). A sustainable methodology of extraction can be developed to minimize energy use, minimize waste contaminants and minimize the factors that contribute to environmental sustainability of insect protein that makes it competitive with conventional sources of protein already in market.

2. Product Development: The development of insect-based food products ought to be aimed at a wide assortment of food products in forms of protein bars, pasta, snacks, ready-to-eat meals, and beverages (Skotnicka *et al*., 2021). Improving taste, texture, and appearance will enhance market appeal. Consumers can further accept more and increase the value of the product through functional foods that have advantages to gut health and nutritionally added foods.

3. Genetic Improvement: Selective breeding on genetics has to be worked upon in future to improve the insect protein content, feed efficiency, and duration of disease resisting power (Hansen *et al*., 2025). It is possible to enhance growth, productivity and environmental flexibility with CRISPR-Cas9. The invention of additional species related to domestication will also grow cost-efficient insect farming.

4. Supply Chain Optimization: In order to trace insect protein safety and visibility along the supply chains, future research should be centered on resilient traceability systems (Traynor *et al*., 2025). Excellent cold chain models are needed in retaining the quality of the product during transport and storage. When there is a high level of market integration networks among farmers, processors, and retailers, the operation efficiency of the company will improve and help in enhancing the adoption of insect proteins within the food sector.

5. Integration with Circular Economy: The ability of future research to optimize the processing of black soldier fly larvae protein on organic waste should be high-quality (Liu *et al*., 2022). The incorporation of insect (rearing) into conventional agriculture has a potential to increase feed and feed sustainability. Bioplastics, fertilizers, and cosmetics are by-products that are valorized, which provides additional innovation via chitin (Chakravarty &

Edwards, 2022). The investment in such areas will realize the complete potential of insects as a sustainable source of protein to solve food problems in the world.

Strategies to Overcome Challenges:

1. Policy Support: Insect farming could be expedited via government policies such as tax benefits, research and equal parts subsidies (Stull & Patz, 2020). Public-private partnerships can drive innovation, infrastructure, and market access. Quality and consumer confidence will also be guaranteed by the standardization of safety rules that will allow the industry to grow.

2. Consumer Education: Insect protein should be promoted and this can be done through awareness campaigns using visuals and captivating media to present the benefits of insect protein in terms of environmental health, nutritive, and economic benefits (Lisboa *et al.*, 2024). The partnerships with the influencers, chefs, and restaurants can make insect meals normal. Sustainable food systems will be taught to students through educational programs in schools and this will lead to acceptance in the long run.

3. Product Innovation: The addition of insect protein to powders, flours, and processed foods will allow avoiding consumer reluctance and hide the presence of this food source (Acosta-Estrada et al., 2021). Protein of insect is used by many producers in the production of smoothies, snacks, and baked goods because it is nutritious. Food science also improves people.

4. Sustainability Metrics: The involvement of customers in insect farming increases as the companies focus on the minimal land consumption, reduced emissions, and high efficiency of using water. Verifiable sustainability data, eco-certifications, and transparent labelling build trust. To raise consciousness, the packaging has clear graphics that compare the carbon footprint with normal foods. Overcoming barriers will demand a two-fold strategy to make sustainable and nutrition-secure future go mainstream.

Conclusion:

The future sustainability is based on the selection of the Protein Revolution and in this case, insect-based protein is significant. The insects provide a radical solution to world ills, as they help to deal with nutritional insufficiencies, food security, and global sustainability. As the global demand on food rises as the planet gets more populated, edible insect farming solves the problem of expensive and non-calorie-dense protein sources such as animals. Bugs process feed into protein better than livestock, using less resources and producing a lesser amount of greenhouse gas. Nutritional advantages provided by the protein, essential amino acids, and microelements content of edible insects are of critical importance to the food-vulnerable populations. We can break debilitating cultural barriers and regulatory barriers with a focus on consumer education, maximization of caring farming and adoption of favorable policies, by scaling up production in farming. There is need to have the food industry introduce edible insects as a form of sustainable protein as a way of meeting the demands pf a diverse global population. The short-term food security and future resilient, diversified, and environmentally sustainable food system will be the benefits of accepting insects as a feasible food alternative. Such a change will not only be feeding humanity but will be saving our planet making future sustainability. Sustainable and efficient production of food will be a must to feed the world at the future.

References:

1. Abajue, M. C., & Gbarakoro, T. N. (2023). Prospects of insect farming for food security, environmental sustainability, and as an alternative to agrochemical use. In *One Health Implications of Agrochemicals and their Sustainable Alternatives* (pp. 565-600). Singapore: Springer Nature Singapore.
2. Abbasi, E. (2025). Edible insects as a sustainable and innovative approach to addressing global food security and

environmental challenges: a comprehensive review. *Journal of Insects as Food and Feed*, *1*(aop), 1-12.

3. Abro, Z., Kassie, M., Tanga, C., Beesigamukama, D., & Diiro, G. (2020). Socio-economic and environmental implications of replacing conventional poultry feed with insect-based feed in Kenya. *Journal of Cleaner Production*, *265*, 121871.
4. Acosta-Estrada, B. A., Reyes, A., Rosell, C. M., Rodrigo, D., & Ibarra-Herrera, C. C. (2021). Benefits and challenges in the incorporation of insects in food products. *Frontiers in nutrition*, *8*, 687712.
5. Adamtey, N., Badu, E., Ayimba, N., Kimathi, F., & Gebrezgabher, S. (2024). Black soldier fly farming for feed and biofertilizer: a practical guide.
6. Agbemafle, I. (2020). *Alternative protein and iron sources for infant and young child nutrition* (Doctoral dissertation, Iowa State University).
7. Ardoin, R., & Prinyawiwatkul, W. (2020). Product appropriateness, willingness to try and perceived risks of foods containing insect protein powder: A survey of US consumers. *International Journal of Food Science and Technology*, *55*(9), 3215-3226.
8. Bento de Carvalho, T., Teixeira, P., & Barbosa, J. B. (2025). Edible insects and food safety: providing scientific insights for the agro-food sector. *Critical Reviews in Food Science and Nutrition*, 1-19.
9. Chakravarty, J., & Edwards, T. A. (2022). Innovation from waste with biomass-derived chitin and chitosan as green and sustainable polymer: a review. *Energy Nexus*, *8*, 100149.
10. Danks, H. V. (2000). Dehydration in dormant insects. *Journal of Insect Physiology*, *46*(6), 837-852.
11. de Gier, S., & Verhoeckx, K. (2018). Insect (food) allergy and allergens. *Molecular immunology*, *100*, 82-106.
12. Dossey, A. T., Morales-Ramos, J. A., & Rojas, M. G. (Eds.). (2016). *Insects as sustainable food ingredients: production, processing and food applications*. Academic Press.
13. Guiné, R. P., Correia, P., Coelho, C., & Costa, C. A. (2021). The role of edible insects to mitigate challenges for sustainability. *Open Agriculture*, *6*(1), 24-36.
14. Hansen, L. S., Laursen, S. F., Bahrndorff, S., Sørensen, J. G., Sahana, G., Kristensen, T. N., & Nielsen, H. M. (2025). The unpaved road towards efficient selective breeding in insects for food and feed—A review. *Entomologia Experimentalis et Applicata*, *173*(6), 498-521.
15. Hawkey, K. J., Lopez-Viso, C., Brameld, J. M., Parr, T., & Salter, A. M. (2021). Insects: a potential source of protein and other nutrients for feed and food. *Annual review of animal biosciences*, *9*(1), 333-354.
16. Hermans, W. J., Senden, J. M., Churchward-Venne, T. A., Paulussen, K. J., Fuchs, C. J., Smeets, J. S., ... & van Loon, L. J. (2021). Insects are a viable protein source for human consumption: from insect protein digestion to postprandial muscle protein synthesis in vivo in humans: a double-blind randomized trial. *The American journal of clinical nutrition*, *114*(3), 934-944.
17. Jain, I., Kaur, R., Kumar, A., Paul, M., & Singh, N. (2024). Emerging protein sources and novel extraction techniques: a systematic review on sustainable approaches. *International Journal of Food Science & Technology*, *59*(10), 6797-6820.
18. Kipkoech, C. (2023). Beyond proteins—Edible insects as a source of dietary fiber. *Polysaccharides*, *4*(2), 116-128.
19. Kumar, P., Mehta, N., Abubakar, A. A., Verma, A. K., Kaka, U., Sharma, N., ... & Lorenzo, J. M. (2023). Potential alternatives of animal proteins for sustainability in the food sector. *Food Reviews International*, *39*(8), 5703-5728.

20. Lisboa, H. M., Nascimento, A., Arruda, A., Sarinho, A., Lima, J., Batista, L., ... & Andrade, R. (2024). Unlocking the Potential of Insect-Based Proteins: Sustainable Solutions for Global Food Security and Nutrition. *Foods*, *13*(12), 1846.
21. Liu, T., Klammsteiner, T., Dregulo, A. M., Kumar, V., Zhou, Y., Zhang, Z., & Awasthi, M. K. (2022). Black soldier fly larvae for organic manure recycling and its potential for a circular bioeconomy: A review. *Science of the Total Environment*, *833*, 155122.
22. Madau, F. A., Arru, B., Furesi, R., & Pulina, P. (2020). Insect farming for feed and food production from a circular business model perspective. *Sustainability*, *12*(13), 5418.
23. Moruzzo, R., Mancini, S., & Guidi, A. (2021). Edible insects and sustainable development goals. *Insects*, *12*(6), 557.
24. Mwangi, M. N., Oonincx, D. G., Stouten, T., Veenenbos, M., Melse-Boonstra, A., Dicke, M., & Van Loon, J. J. (2018). Insects as sources of iron and zinc in human nutrition. *Nutrition research reviews*, *31*(2), 248-255.
25. Noble-Nesbiti, J. (1990). Insects and their water requirements. *Interdisciplinary Science Reviews*, *15*(3), 264-282.
26. Nowakowski, A. C., Miller, A. C., Miller, M. E., Xiao, H., & Wu, X. (2022). Potential health benefits of edible insects. *Critical Reviews in Food Science and Nutrition*, *62*(13), 3499-3508.
27. Oonincx, D. G., Van Broekhoven, S., Van Huis, A., & Van Loon, J. J. (2015). Feed conversion, survival and development, and composition of four insect species on diets composed of food by-products. *PloS one*, *10*(12), e0144601.
28. Oonincx, D. G., Van Itterbeeck, J., Heetkamp, M. J., Van Den Brand, H., Van Loon, J. J., & Van Huis, A. (2010). An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption. *PloS one*, *5*(12), e14445.
29. Puteri, B., Jahnke, B., & Zander, K. (2023). Booming the bugs: How can marketing help increase consumer acceptance of insect-based food in Western countries? *Appetite*, *187*, 106594.
30. Raven, P. H., & Wagner, D. L. (2021). Agricultural intensification and climate change are rapidly decreasing insect biodiversity. *Proceedings of the National Academy of Sciences*, *118*(2), e2002548117.
31. Ribeiro, J. C., Cunha, L. M., Sousa-Pinto, B., & Fonseca, J. (2018). Allergic risks of consuming edible insects: A systematic review. *Molecular nutrition & food research*, *62*(1), 1700030.
32. Rutherford, J. A., Elliott, R. M., Knott, G. P., Thatcher, R., & Manders, R. J. (2025). Insect protein to support human skeletal muscle anabolism: A systematic review of randomised controlled trials. *Nutrition reviews*, nuae218.
33. Sajid, Q. U. A., Asghar, M. U., Tariq, H., Wilk, M., & Płatek, A. (2023). Insect meal as an alternative to protein concentrates in poultry nutrition with future perspectives (an updated review). *Agriculture*, *13*(6), 1239.
34. Siddiqui, S. A., Mahanta, D. K., Bhoi, T. K., Ahmad, A., & Fernando, I. (2024). Mopane worm (Gonimbrasia belina)-An exclusive African edible insect as human food-A comprehensive review. *Future Foods*, 100438.
35. Siddiqui, S. A., Tettey, E., Yunusa, B. M., Ngah, N., Debrah, S. K., Yang, X., ... & Shah, M. A. (2023). Legal situation and consumer acceptance of insects being eaten as human food in different nations across the world–A comprehensive review. *Comprehensive Reviews in Food Science and Food Safety*, *22*(6), 4786-4830.
36. Siddiqui, S. A., Zannou, O., Karim, I., Kasmiati, Awad, N. M., Gołaszewski, J., ... & Smetana, S. (2022). Avoiding food

neophobia and increasing consumer acceptance of new food trends—A decade of research. *Sustainability*, *14*(16), 10391.
37. Skotnicka, M., Karwowska, K., Kłobukowski, F., Borkowska, A., & Pieszko, M. (2021). Possibilities of the development of edible insect-based foods in Europe. *Foods*, *10*(4), 766.
38. Stull, V., & Patz, J. (2020). Research and policy priorities for edible insects. *Sustainability Science*, *15*, 633-645.
39. Tao, J., & Li, Y. O. (2018). Edible insects as a means to address global malnutrition and food insecurity issues. *Food Quality and Safety*, *2*(1), 17-26.
40. Traynor, A., Burns, D. T., Wu, D., Karoonuthaisiri, N., Petchkongkaew, A., & Elliott, C. T. (2024). An analysis of emerging food safety and fraud risks of novel insect proteins within complex supply chains. *npj Science of Food*, *8*(1), 7.
41. Van Huis, A., & Oonincx, D. G. (2017). The environmental sustainability of insects as food and feed. A review. *Agronomy for Sustainable Development*, *37*, 1-14.
42. Veldkamp, T., Meijer, N., Alleweldt, F., Deruytter, D., Van Campenhout, L., Gasco, L., ... & Van der Fels-Klerx, H. J. (2022). Overcoming technical and market barriers to enable sustainable large-scale production and consumption of insect proteins in Europe: A SUSINCHAIN perspective. *Insects*, *13*(3), 281.
43. Wijesekara, T., & Xu, B. (2024). New insights into sources, bioavailability, health-promoting effects, and applications of chitin and chitosan. *Journal of Agricultural and Food Chemistry*, *72*(31), 17138-17152.
44. Wu, G. (2020). Metabolism and functions of amino acids in sense organs. *Amino Acids in Nutrition and Health: Amino acids in systems function and health*, 201-217.

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Best Organic Practices for Disease-Free Vegetable Farming

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Organic vegetable farming presents a sustainable and environmentally friendly alternative to conventional agricultural methods by reducing reliance on synthetic pesticides and fertilizers. One of the major challenges in vegetable production is managing diseases caused by fungi, bacteria, and viruses. In traditional farming, these are often addressed with repeated chemical applications, which can lead to negative outcomes such as the development of resistant pathogens, degradation of soil health, contamination of water sources, and harmful residues on produce. Organic farming provides a more holistic solution by focusing on prevention and building a resilient farming system. The foundation of organic disease management lies in enhancing soil health. Regular use of compost, farmyard manure (FYM), and vermicompost increases beneficial microbial activity and improves soil structure. Incorporating green manure crops such as sunhemp and dhaincha into the soil further boosts fertility and suppresses soil-borne diseases. The application of biofertilizers like Azotobacter, Phosphobacteria, and Trichoderma supports balanced nutrient availability and strengthens plants' natural resistance. Preventative seed treatments using natural substances such as *Trichoderma viride*, neem extract, cow urine, and traditional blends like turmeric and ash help protect seedlings from early infections and promote healthy germination. Selecting and planting disease-resistant crop varieties also plays a key role in reducing the incidence of plant diseases. When infections do occur, organic solutions such as bio fungicides (e.g., *Trichoderma viride*, *Pseudomonas fluorescens*) and natural plant-based sprays (e.g., neem oil, garlic-chili extract, fermented cow dung and urine) are used effectively. These methods are safe, eco-friendly, and cost-efficient. Additionally, cultural practices like crop rotation, maintaining proper plant spacing, using raised beds, and early morning irrigation contribute significantly to disease prevention. Overall, adopting organic disease management practices supports healthier crops, improves yield, reduces production costs, and ensures environmental and consumer safety-making it a practical and sustainable choice for modern vegetable farming.

Key Words: Organic farming, Disease management, Trichoderma, Biofertilizers

Introduction

Growing vegetables without chemicals is not only achievable—it is a smarter, more sustainable approach to agriculture that offers both economic and ecological benefits. With rising concerns over soil degradation, pesticide residues, and environmental pollution, organic vegetable farming has emerged as a viable and eco-friendly alternative to conventional chemical-intensive methods. This approach promotes the cultivation of crops using natural inputs and emphasizes the health of the entire agroecosystem, including the soil, plants, and surrounding environment. One of the biggest obstacles in vegetable production is the occurrence of diseases caused by pathogens such as fungi, bacteria, and viruses. In conventional farming, these diseases are typically managed with synthetic fungicides, bactericides, and pesticides. While these chemicals may provide short-term control, their continuous use has led to several problems: increased resistance in pathogens, contamination of water sources, soil nutrient imbalances, and potential health risks to both farmers and consumers.

Organic farming tackles these challenges through a preventive and systemic approach to disease management. Instead of targeting individual diseases reactively, organic practices aim to create conditions where plants are less likely to get sick in the first place. At the heart of this strategy is the enhancement of soil health. Healthy, biologically active soil supports robust plant growth and natural resistance to pathogens. This can be achieved through the regular application of compost, vermicompost, green manures, and microbial biofertilizers such as *Azotobacter*, *Phosphobacteria*, and *Trichoderma*. Seed treatment with organic materials is also a critical first step in disease prevention. Using natural agents such as *Trichoderma viride*, neem extracts, cow urine, or even traditional mixtures of turmeric and ash, seeds can be protected from early-stage infections. These methods not only prevent fungal and bacterial attacks but also boost germination and early plant vigor. Another effective strategy is the selection and use of disease-resistant or tolerant crop varieties. For instance, certain tomato and cucumber varieties have been bred to resist specific diseases like Fusarium wilt or powdery mildew. Incorporating these varieties reduces the risk of major disease outbreaks and minimizes the need for any intervention.

When diseases do occur, organic farmers rely on biological controls and natural remedies. Biofungicides such as *Trichoderma viride* and *Pseudomonas fluorescens* help suppress pathogens without harming beneficial organisms. Additionally, natural sprays made from neem oil, garlic-chili extract, buttermilk, or fermented cow dung and urine serve as effective alternatives to synthetic chemicals. These remedies are not only cost-effective but also easy to prepare and safe for the environment. Cultural practices and farm hygiene also play a significant role in organic disease management. Techniques such as crop rotation, proper plant spacing, raised bed planting, and controlled irrigation reduce the risk of disease by creating an unfavorable environment for pathogens. For example, watering at the base of plants early in the day reduces leaf wetness-a common trigger for fungal infections. Removing diseased plants, using clean tools, and rotating crop families annually are simple yet powerful practices that help maintain a healthy farm ecosystem.

Organic disease management in vegetable farming is about more than avoiding chemicals, it's about adopting a holistic, proactive system that fosters plant health and ecological balance. With growing awareness and consumer demand for safe, sustainably grown food, these organic methods offer farmers a clear path toward resilient, productive, and environmentally sound agriculture.

1. The Importance of Organic Disease Management

Conventional farming relies heavily on repeated use of fungicides and pesticides to control plant diseases, which can cause issues like pathogen resistance, soil damage, water pollution, and harmful residues on crops. Organic farming focuses instead on preventing diseases by enhancing soil health, biodiversity, and plant strength to naturally reduce disease outbreaks (Lal, 2020).

2. Strengthening the Foundation: Building Healthy Soil

Applying organic compost, FYM, or vermicompost enhances soil health by increasing microbial activity and humus content. Growing green manure crops like sunhemp and dhaincha and incorporating them into the soil at flowering improves soil structure and fertility by adding organic matter and boosting microbial activity (Tomar *et al.*, 2019). Biofertilizers are essential in organic farming as they enhance nutrient availability and boost crop growth. Rhizobium fixes nitrogen in legumes, while *Azotobacter* and *Azospirillum* do the same for non-legumes. Phosphate Solubilizing Bacteria increase phosphorus availability, and Arbuscular Mycorrhizal Fungi improve phosphorus absorption by expanding the root system (Kumar *et al.*, 2024). Trichoderma is especially effective as it colonizes roots, suppresses fungi like *Fusarium*, *Rhizoctonia*, and *Pythium* (Kamal *et al* ., 2018).

3. Seed Treatment: The First Line of Defense

Diseases often start at the seed level. Organic seed treatment prevents early-stage infection and gives the seedling a strong start.

Organic Seed Treatment Methods:

- **Trichoderma viride**: Mix 5–10g per kg of seed before sowing.
- **Panchagavya soak**: Soak seeds for 20 minutes to energize and protect.
- **Cow urine or diluted neem leaf extract**: Acts as a natural disinfectant.
- **Turmeric and ash**: Traditional method for protecting against fungal spores.

  Source: Sharma and Singh, 2020

4. Use of Disease-Resistant Varieties

Developing and using disease-resistant crop varieties is a key strategy in preventing plant diseases.

Crop	Disease	Varieties/F1 hybrids resistance to disease
Tomato	Bacterial wilt	Arka Abha, Arka Abhijit, Utkal Pallvai (BT1), Utkal Kumari (BT10), Arka Alok, Arka Vardhan F1 hybrids-Arka Rakshak, Arka Ananya, Arka Samrat, Arka shreshta
	Leaf curl virus	Hisar Anmol(H-24), Hisar Arun (H36), H-88 F1 hybrids-Arka Rakshak, Arka Ananya, Arka Samrat
Brinjal	Little leaf	Pusa Purple Cluster, Hisar Shyamal, Pant Rituraj
	Phomopsis blight	Pusa Bhairav, Pusa Purple Cluster
Chilli	Bacterial wilt	Ujjwala, Anugraha, Pant C-1, Punab Lal
	Thrips, CMV, TMV, TLCV	Pusa Jwala, Pusa Sadabahar, Pant C-1
	Mites & Aphids	Punjab Lal, Pant C-1
Okra	Yellow vein mosaic virus	Pusa Bhindi-5, Varsha Uphar, Arka Anamika, Arka Abhay, Punajb Padmini, Punjab-7, Punjab-8, Hisar Unnat, Azad Kranti, Utkal Gourav
Pea	Powdery mildew	JP-83, JP-4, Arka Ajit, JP179, Arka Karthik, Arka Sampoorna (snap pea), JP9
	Rust	JP. Batri Brown 3, JP. Batri Brown 4, JP179, Arka Karthik, Arka Sampoorna (snap pea)
Water melon	Anthracnose, Downy mildew, Powdery mildew	Arka Manik

Source: Tomar *et al*., 2019

5. Organic Disease Control Measures

Even with all precautions, some diseases may still occur. Here are **organic remedies** to control them:

a) Biological Control Agents (Biofungicides)

Biological control involves using living organisms to combat plant pathogens and is a valuable alternative to chemical use in organic farming. They are safe for humans and the environment since they do not leave harmful chemical residues (Pegu and Kachari, 2024) These naturally suppress pathogens and strengthen plant immunity. Such as ***Trichoderma viride***- Apply in soil or as foliar spray. ***Pseudomonas fluorescens***- Effective against leaf spot and blight. **Neem cake-** Mix in soil to deter nematodes and fungal growth (Kaur *et al*., 2017).

b) Organic Sprays

Apply once every 7–10 days during disease-prone seasons.

Organic Spray	Preparation	Controls	Reference
Neem oil spray	30 ml neem oil + 5 ml soap/litre of water	Fungal & sucking pests	Isman, 2006
Garlic-chili extract	Grind 100g garlic + 50g chili + 1L water, ferment 24 hrs	Bacterial & fungal diseases	Okwute and Egwu, 2013
Butter milk spray	Dilute 1 part buttermilk with 4 parts of water	Powdery mildew	Joshi and Bhargava, 2012
Cow dung + cow urine mix	Ferment 1:2 ratio for 7 days, then dilute 1:10	General disease resistance	Singh and Singh, 2015

6. Cultural and Hygiene Practices

Sometimes simple farm hygiene such as proper spacing, crop rotation, sanitation, remove and destroy diseased plants, avoid overcrowding, using raised beds and proper irrigation practices can prevent major disease outbreaks (Sharma *et al*., 2014).

Case study

Shankar Lal, a farmer from Rajasthan, successfully reduced Fusarium wilt by 80% and improved yields in his tomato and chilli crops by using organic methods like Trichoderma seed treatment, neem cake, and organic sprays. He now sells his produce as organic, earning a 20% higher price, showing the benefits of organic disease management.

Conclusion

Organic disease management is not merely about substituting chemical inputs with natural ones—it's about transforming the entire farming system to promote plant health and ecological balance. By focusing on preventive strategies such as enhancing soil fertility, using disease-resistant varieties, treating seeds naturally, and maintaining good farm hygiene, farmers can effectively reduce disease outbreaks. Affordable methods like composting, applying biofungicides, using neem-based sprays, and practicing crop rotation not only help control plant diseases but also lower input costs and improve crop quality. The experience of farmers like Shankar Lal from Rajasthan demonstrates that organic practices can significantly boost productivity and income while protecting human health and the environment. In essence, organic disease management supports a sustainable, resilient, and profitable approach to vegetable farming.

Reference:

Isman, M. B. 2006. Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. *Annual Review of Entomology*, 51, 45-66.

Joshi, S and Bhargava, P. 2012. Effectiveness of buttermilk and other organic treatments against powdery mildew of cucumber. *Journal of Plant Pathology*, 94(3), 579-584.

Kamal, R. K., Athisayam, V., Gusain, Y. S and Kumar, V. 2018. Trichoderma: A most common biofertilizer with multiple roles in agriculture. *Biomedical Journal of Scientific and Technical Research*, 4(1), 1–5.

Kaur, M., Kaur, J and Singh, H. 2017. Role of Bioagents in Sustainable Agriculture. *Journal of Plant Pathology and Microbiology*, 8(10), 418.

Kumar, M.S., Nair, A.K., Kalaivanan, D., Hebbar, S.S., Prabhakar, M and Sridevi, V. 2024. Organic Farming Practices in Vegetable Crops. Advances in Organic Farming: Crop Production and Management (pp. 381-403). Apple Academic Press.

Lal, R. 2020. Soil health and organic farming: Pathways to sustainable agriculture. *Sustainability*, 12(2), 571.

Okwute, S. K and Egwu, G. O. 2013. Antimicrobial properties of garlic (*Allium sativum*) and chili pepper (*Capsicum* spp.) extracts on bacterial pathogens. *International Journal of Scientific Research in Environmental Sciences*, 1(2), 16-22.

Pegu, J and Kachari, M. 2024. Organic Disease Management of Solanaceous Vegetable Crops. Advances in Organic Farming: Crop Production and Management (pp. 605-620). Apple Academic Press.

Sharma, P., Singh, D and Meena, P. D. 2014. Integrated disease management in vegetable crops. *Indian Journal of Agricultural Sciences*, 84(8), 915–927.

Singh, R and Singh, A. 2015. Use of Panchagavya and organic mixtures in crop protection and soil health improvement. *International Journal of Agricultural Sciences*, 11(4), 233-239.

Tomar, B. S., Jat, G. S and Singh, J. 2019. Organic vegetable production: principles and practices. *Modern Concepts and Practices of Organic Farming for Safe Secured and Sustainable Food Production*, 3

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Vegetable Waste to Wealth: Circular Economy in Agriculture

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In an era of increasing global food insecurity and environmental concerns, vegetable waste presents both a challenge and an opportunity. Every year, millions of tonnes of vegetable waste are discarded across the value chain-from farm fields to retail markets. However, instead of being seen as a burden, this organic waste can be transformed into valuable products such as compost, bioenergy, animal feed, bioplastics, and plant-based extracts. This article explores how the principles of the circular economy can be applied to vegetable waste management, thereby converting "waste into wealth" while promoting sustainable agriculture, environmental protection, and rural livelihoods.

Key words: Bioplastics, Bioenergy, Biochar

Introduction:

Vegetables are essential for human health, but their perishable nature makes them one of the most wasted food categories worldwide. According to FAO estimates, about 30-40% of all vegetables produced are lost or wasted annually due to poor handling, market rejection, or post-harvest losses (FAO, 2013). In traditional linear food systems, this waste ends up in landfills, generating methane and contributing to climate change. The concept of a circular economy seeks to redesign this model by promoting reuse, recycling, and value addition. By tapping into this philosophy, vegetable waste can become a resource-fueling new products and industries in a sustainable manner. This shift is vital for resource efficiency, environmental health, and income generation for farmers and entrepreneurs alike.

What is Circular Economy in Agriculture:

A circular economy aims to reduce waste, reuse resources, and recycle nutrients back into the system unlike the traditional linear model of “produce-use-dispose.” In agriculture, this means making the most out of every resource, from crop residues to market waste, and turning by-products into new products. When applied to vegetable production, this concept opens up a wealth of opportunities not just for waste management, but for income generation, soil health improvement, renewable energy, and sustainable farming practices.

Sources of Vegetable Waste: Vegetable waste is generated at multiple stages:

Field Waste: Damaged or undersized produce left during harvest

Post-harvest Losses: Spoilage during transport or storage

Market Waste: Unsold or rotting produce at mandis and retail stores

Household Waste: Peels, stems, and unused portions

In India alone, over 30% of vegetables are wasted a figure that highlights both a problem and an opportunity.

Turning Vegetable Waste into Wealth:

Composting: Black Gold for the Soil

Feeding the Soil Vegetable peels, stalks, and spoiled produce are rich in organic matter and nutrients. Through aerobic composting, these residues can be converted into high-quality compost that enriches the soil, improves water retention, and reduces the need for chemical fertilizers. Small-scale composting units at farms and municipal markets have proven highly effective in managing waste sustainably (Ghosh *et al*., 2021).

Bioenergy: Fueling Farms with Waste

Turning Rot into Power Anaerobic digestion of vegetable waste can generate biogas, a clean fuel for cooking or electricity generation. This method not only reduces greenhouse gas emissions but also produces digest, a nutrient rich slurry that can be used as fertilizer.

Biochar: A Carbon-Rich Soil Enhancer

By converting vegetable waste into biochar through pyrolysis (burning in low oxygen), which helps to improve soil fertility and moisture retention, lock carbon in the soil for years, reduce greenhouse gas emissions.

Animal Feed: Nutrition from Waste:

A Second Life for Leftovers Vegetable residues such as leafy greens, cabbage outer leaves, and tomato pulp can serve as low-cost cattle or poultry feed after minimal processing. This reduces the cost of livestock production while cutting waste.

Bio-based Packaging and Bioplastics: Innovations in green packaging now use vegetable waste like potato peel starch or tomato skins to make biodegradable films and containers. These alternatives to plastic can drastically reduce agro-industrial waste and pollution (Siracusa *et al*., 2008).

Value-Added Products and Extracts: Vegetable waste contains bioactive compounds such as antioxidants, flavonoids, and pigments. These can be extracted and used in cosmetics, nutraceuticals, and natural dyes.

Challenges in Waste-to-Wealth Conversion:

While the potential is vast, several barriers must be addressed like

- Lack of infrastructure and awareness in rural and semi-urban areas
- High initial investment costs for bio-processing technologies
- Regulatory gaps for marketing products like bioplastics or animal feed from waste
- Poor segregation of biodegradable waste at source

Collaborative efforts involving government policy, private investment, research institutions, and farmer cooperatives are essential to overcome these hurdles.

Conclusion:

Vegetable waste, if managed through the lens of a circular economy, can shift the paradigm from pollution to production. By converting biodegradable waste into compost, bioenergy, animal feed, and high-value products, farmers and entrepreneurs can create green jobs, restore soil health, and reduce carbon footprints. The "waste-to-wealth" approach not only supports sustainable agriculture but also moves us closer to achieving zero-waste food systems in alignment with the Sustainable Development Goals. Now more than ever, it is time to see vegetable waste not as garbage, but as a goldmine.

References:

FAO. (2013). Food wastage footprint: Impacts on natural resources. Food and Agriculture Organization of the United Nations.

Ghosh, A., Barman, N., & Das, S. (2021). Composting of vegetable market waste for sustainable soil management. *Indian Journal of Agricultural Sciences*, 91(3), 379-384.

Kumar, A., & Jain, S. (2018). Management of vegetable waste for animal feed: A review. *Journal of Cleaner Production*, 180, 373-386.

Siracusa, V., Rocculi, P., Romani, S., & Dalla Rosa, M. (2008). Biodegradable polymers for food packaging: A review. Trends in Food Science & Technology, 19(12), 634-643.

Ravindran, R., & Jaiswal, A. K. (2016). Exploitation of vegetable waste for value-added products. Trends in Biotechnology, 34(1), 58-69.

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"Quinoa: Cultivating Resilience and Nutrition for Tomorrow"

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In recent years, quinoa (pronounced **keen-wah**) has taken the world by storm, making its way from ancient Andean terraces to supermarket shelves and kitchen tables across the globe. Once a sacred staple of the Inca civilization, this tiny, nutrient-dense seed is now hailed as a "superfood" and a crop of the future. But what exactly makes quinoa so special? And why are scientists, farmers, and policymakers increasingly looking to quinoa as a solution to global food security challenges? This article explores quinoa's journey, its unique characteristics, and its vast potential as a resilient, nutritious, and sustainable crop for the 21st century.

The Ancient Grain with a Modern Mission

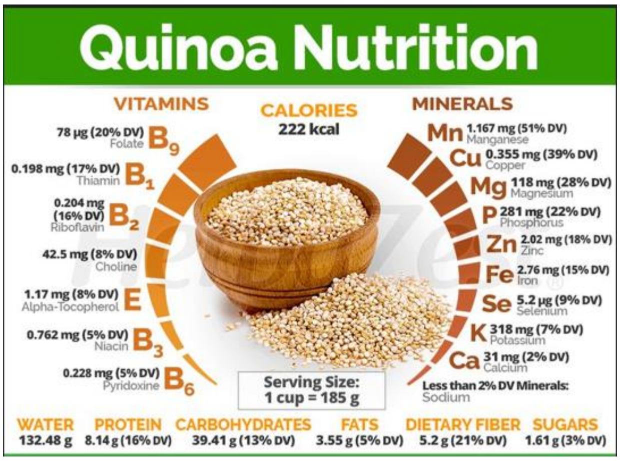
Quinoa has been cultivated in the Andes Mountains of South America for over 5,000 years. It was a central component of the Inca diet and was revered as the "mother grain." Spanish conquistadors attempted to suppress its cultivation in favor of European crops, but the indigenous people preserved it in isolated mountain regions of Bolivia, Peru, and Ecuador. Fast-forward to the 21st century, quinoa emerged on the global stage as Western consumers became more health-conscious. The United Nations declared 2013 the *International Year of Quinoa*, recognizing its high nutritional value, biodiversity, and adaptability to adverse climates. This declaration was not only symbolic but also strategic-pointing to quinoa's potential role in addressing food insecurity, climate change, and malnutrition.

What is Quinoa? A Closer Look

Though commonly referred to as a grain, quinoa is technically a *pseudo-cereal*—it doesn't belong to the grass family like wheat or rice. It's related to beets, spinach, and amaranth. Quinoa seeds come in a variety of colors, including white, red, and black, and have a slightly nutty flavor and fluffy texture when cooked. But quinoa is not just about taste—it's a nutritional powerhouse.

Nutritional Goldmine

- **Complete Protein:** Unlike most plant-based foods, quinoa contains all nine essential amino acids, making it an excellent protein source for vegetarians and vegans.
- **High Fiber:** Quinoa is rich in dietary fiber, aiding digestion and promoting satiety.
- **Rich in Vitamins and Minerals:** It provides significant amounts of magnesium, iron, zinc, potassium, and B vitamins.
- **Gluten-Free:** Naturally gluten-free, quinoa is ideal for people with celiac disease or gluten intolerance.
- **Low Glycemic Index:** Its slow-digesting carbohydrates help regulate blood sugar levels.



Source: USDA nutritional database

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Agronomic Strengths: Why Quinoa Can Thrive Where Other Crops Fail

Agronomic Strength	Description
Drought Tolerance	Quinoa can survive with minimal water, making it ideal for regions experiencing increased drought due to climate change.
Salt Tolerance	Naturally salt-tolerant, quinoa can grow in saline soils and is suitable for degraded lands or coastal areas affected by saltwater intrusion.
Wide Climatic Adaptation	Capable of thriving from sea level to 4,000 meters and in temperatures ranging from -8°C to 38°C, quinoa is highly adaptable to diverse environments.
Low Input Requirements	Requires fewer chemical fertilizers and pesticides compared to conventional crops, making quinoa more sustainable and accessible for smallholder farmers.

One of the most remarkable qualities of quinoa is its resilience. It can grow in diverse and harsh environments, from high-altitude Andean plateaus to saline deserts. Here are some reasons why quinoa is being considered a climate-smart crop:

Global Expansion of Quinoa: From Andean Staple to Worldwide Super Crop

Driven by increasing global demand, quinoa cultivation has expanded far beyond its native South America and is now grown in more than 120 countries. Regions such as the United States, Canada, France, India, Kenya, and China have embraced this resilient crop. In Africa, particularly within the Sahel region, several nations are piloting quinoa projects as a strategy to combat malnutrition and enhance food security. Its natural drought resistance makes it especially well-suited for the continent's dryland areas. Across Asia, countries like India, Nepal, and China are exploring quinoa's potential in mountainous and semi-arid zones. In India, experimental cultivation in regions like Rajasthan and Ladakh has shown encouraging results. Meanwhile, in Europe and North America, quinoa is grown in countries such as France, Spain, and the United States-especially in Colorado and California-often using advanced agricultural technologies. While this global expansion is promising, it also presents several challenges, including the need for genetic adaptation to local environments, effective pest management, and the development of strong market infrastructure to support new producers.

Socioeconomic Impacts: A Double-Edged Sword

The quinoa boom brought prosperity to many Andean farmers, with export prices peaking around 2014. However, it also introduced complex socioeconomic dynamics.

Pros	Cons
Increased Income: Farmers in Bolivia and Peru gained from high export prices.	**Price Volatility:** Post-2014, prices fell due to overproduction and competition, reducing farmer earnings.
Empowerment: Women's cooperatives and smallholder associations grew around quinoa.	**Food Access:** High prices during peak demand made quinoa unaffordable for some local consumers.
Local Innovation: Traditional farming was revitalized with modern techniques.	**Monoculture Risks:** Over-cultivation without rotation caused soil degradation and reduced biodiversity.

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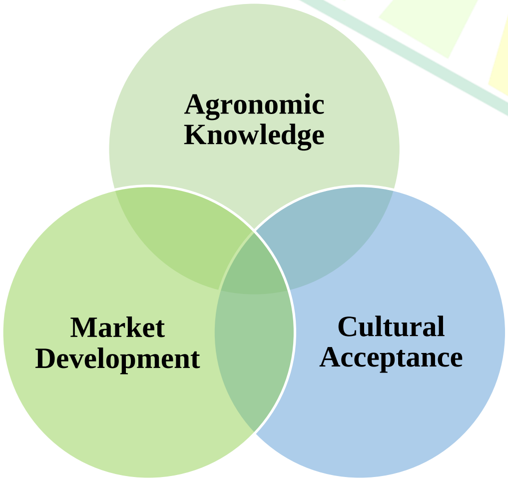
Quinoa and Food Security: A Match Made in Policy Heaven?

With nearly 828 million people undernourished globally (FAO, 2022), diversified food systems are essential. Quinoa's unique properties offer a multi-pronged approach to food security:

Benefit	Description
Nutritional Security	Its high protein and micronutrient content help combat malnutrition, especially in regions where diets are dominated by low-nutrient cereals.
Climate Resilience	Quinoa's tolerance to drought, frost, and salinity makes it a reliable crop in the face of increasing weather extremes due to climate change.
Income Diversification	Offers smallholder farmers in marginal lands a high-value alternative to conventional crops, helping boost rural livelihoods.
Crop Diversification	Including quinoa in crop rotations improves soil health, disrupts pest cycles, and supports agroecological sustainability.

Quinoa Challenges: Not a Silver Bullet

Despite its potential, quinoa is not without challenges:



- Quinoa is still a relatively new crop in many parts of the world. Farmers need access to adapted seeds, extension services, and knowledge of best practices.
- Without proper marketing, processing, and consumer awareness, quinoa can struggle to find a foothold in new regions.
- Genetic diversity is essential. Open-source, non-GMO seed varieties suited for different climates are needed.
- In regions where rice, wheat, or maize dominate, introducing quinoa requires education on cooking and nutrition.

The Culinary Revolution: From Trend to Tradition

What started as a health-food trend has now become a staple in many kitchens. From quinoa salads and soups to energy bars and gluten-free baking, its versatility is unmatched.

Global Cuisine Fusion

Chefs worldwide are incorporating quinoa into both traditional and fusion dishes—quinoa sushi, tabbouleh, dosas, and even biryani. It adapts well to local flavors.

Home Cooks and Health Nuts

Home cooks appreciate its quick cooking time (15–20 minutes), while health enthusiasts praise its protein punch.

Food Industry Innovations

Quinoa flour, quinoa milk, and quinoa pasta are emerging as healthier alternatives to conventional options.

Future Prospects: The Path Ahead

As the world faces overlapping challenges such as climate change, food insecurity, and rising rates of nutrition-related diseases, quinoa emerges as a promising solution for building a more resilient and sustainable food system. However, realizing its full potential will require a coordinated and strategic approach. Continued investment in research and development is crucial—agricultural institutions must focus on breeding climate-resilient, high-yield quinoa varieties that are adapted to diverse ecosystems across the globe. Alongside scientific innovation, strong policy support is essential. Governments should integrate quinoa into national agricultural strategies, provide subsidies where appropriate, and invest in research, extension services, and farmer training programs to facilitate widespread adoption. International collaboration, particularly South-South partnerships such as those between Peru and African nations, can play a vital role in accelerating the exchange of knowledge, technology, and best practices. Importantly, quinoa should not be promoted as a monoculture crop; instead, it must be incorporated into diversified and ecologically sound farming systems to ensure long-term sustainability for both people and the planet.

Conclusion: A Seed of Change

Quinoa is more than just a trendy superfood-it's a symbol of resilience, heritage, and possibility. From the terraced slopes of the Andes to arid plains in Africa, quinoa holds the promise of nourishing both people and the planet. In a world where the future of food is uncertain, this ancient seed might just help sow a new chapter in agriculture—one that's more inclusive, sustainable, and nutritionally secure. The question is no longer *whether* quinoa can be part of that future, but *how* we can make its potential accessible to all.

References:

❖ Bazile, D., Jacobsen, S.-E., & Verniau, A. (2016). *The global expansion of quinoa: Trends and limits*.
❖ ICBA. (2013). *Quinoa: A future-proof crop for marginal environments*
❖ USDA Food Data Central. *Quinoa, cooked* – Nutrient profile database
❖ FAO. (2021). *Quinoa: An ancient crop to contribute to world food security*.

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Insect derived lipids: an overview on their extraction strategies and potential applications with current perspective

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Insect-derived lipids offer a sustainable and effective solution for hydration and moisture retention in cosmetics due to their rich fatty acid composition. These lipids, particularly those extracted from black soldier fly larvae (Hermetia illucens), can be used as emollients, emulsifiers, and stabilizers in skincare products, contributing to improved skin hydration, elasticity, and barrier function.

A Historical Perspective

The use of insect-derived ingredients in cosmetics dates back centuries. Ancient civilizations, such as the Egyptians, incorporated insect extracts into beauty products for pigmentation, fragrance, and preservation. Carminic acid from cochineal insects has been used as a natural red dye in lipsticks and rouges for centuries. The Chinese and Greeks also utilized insect-based substances for medicinal and cosmetic applications, recognizing their beneficial properties for skin protection and rejuvenation. During the Renaissance, crushed insects were commonly used in European cosmetics to create vibrant pigments for makeup and textiles.

Image: Adobe Stock

Cochineal insects are harvested for their red carminic acid dye

The Aztecs and Maya harvested cochineal insects extensively to produce red dyes for both textiles and body painting, demonstrating the long-standing use of insects in enhancing appearance. Even in the 19th century, insect-derived substances like shellac, secreted by the lac bug, were used in hair and nail polishes, further illustrating the historical dependence on insect-based products for aesthetic enhancement.

With the advent of industrialization, synthetic alternatives largely replaced natural insect-based ingredients due to cost and scalability. However, as sustainability concerns rise and natural ingredients regain popularity, biotechnology is bringing insect-derived compounds back into the spotlight. Today, research highlights the potential of insect lipids as an eco-friendly and functional resource in the cosmetics industry, offering a compelling alternative to traditional animal- and plant-based oils. This renewed focus aligns with the cosmetics industry's growing commitment to sustainability and ethical sourcing.

Insect-derived molecules and their benefits

Insects provide various bioactive molecules, including fatty acids, peptides, and lipids which have numerous applications in cosmetics. For example, lauric acid, myristic acid, palmitic acid, and oleic acid are among the most commonly extracted lipids from black soldier fly larvae. These molecules serve as emollients, surfactants, and antimicrobial agents. The high concentration of saturated fatty acids in insect lipids supports skin hydration, elasticity, and repair mechanisms, making them highly functional for dermatological applications.

Unlike traditional plant-based sources such as palm oil, insect lipids offer significant advantages in terms of land and water efficiency, making them a more sustainable option. Moreover, the ability of insects to transform organic waste into valuable cosmetic ingredients enhances their ecological appeal. Additionally, animal-derived lipids are biodegradable, reducing environmental impact compared to synthetic chemicals, thus aligning with green chemistry initiatives in cosmetics.

Extraction of insect-derived compounds

Insect-derived bioactive molecules, including lipids, peptides, and chitosan, are extracted from larvae, pupae, or adult insects through various methods depending on the species and the target compound. Typically, insects are euthanized through freezing or dehydration to preserve their biochemical integrity. Lipids, such as those from black soldier fly larvae, are obtained through mechanical pressing or solvent extraction, while bioactive peptides are derived by enzymatic digestion of mealworm proteins. Chitosan is extracted from insect exoskeletons like those of the silkworm.

Traditional lipid extraction methods, such as solvent-based extraction, often rely on hexane or other petroleum-derived solvents, which can pose environmental and health concerns due to volatile organic compound (VOC) emissions and hazardous waste generation. Emerging technologies such as enzymatic extraction and supercritical CO_2 extraction promise higher purity lipids with minimal environmental impact. Enzymatic extraction utilizes biodegradable enzymes to break down insect biomass in a controlled manner, reducing the need for harsh chemicals while improving lipid recovery efficiency.

Similarly, supercritical CO_2 extraction, a solvent-free process, uses pressurized carbon dioxide to extract lipids, ensuring high purity while eliminating toxic residues. Although these advanced methods require higher initial investment and energy input, they improve the cost efficiency of insect lipid production in the long run by reducing waste, increasing lipid yield, and enhancing sustainability. As research progresses, optimizing these techniques will be crucial for making insect-derived lipids a viable and scalable alternative to traditional plant- and animal-based oils.

Applications of insect lipids in cosmetics

Lauric acid, found in abundance in black soldier fly larvae, possesses antibacterial properties, making it ideal for cleansing products, soaps, and antimicrobial creams. Its natural antimicrobial action makes it suitable for acne-prone skin formulations. Myristic acid, present in mealworms, is widely used in moisturizers and emollients for its skin-conditioning properties, providing a silky and lightweight texture. Palmitic acid contributes to hydration and is commonly included in creams and lotions to enhance texture and moisture retention, offering improved barrier protection. Oleic acid, abundant in crickets and locusts, strengthens the skin barrier and is frequently utilized in anti-aging and hydrating formulations.

These lipid components can also be modified into esters and emulsifiers to improve the stability and absorption of skincare formulations, making them an essential ingredient in advanced dermatological research. Beyond skincare, insect-derived lipids are being explored for their potential in haircare and sun protection products. Their natural lipid profile helps condition hair while offering UV protection, making them a viable alternative to synthetic silicones and mineral oils. The use of these lipids in solid shampoo bars and biodegradable packaging solutions further exemplifies their potential in sustainable beauty innovations.

Key Benefits and Applications:

- **Emollients:**
  Insect lipids, like lauric, myristic, palmitic, and oleic acids, help soften and smooth the skin, reducing water loss and enhancing moisture retention.
- **Emulsifiers:**
  They aid in combining oil and water-based ingredients, creating stable and effective cosmetic formulations.
- **Skin Barrier Function:**
  The fatty acids in insect lipids, particularly linoleic acid, play a vital role in maintaining the skin's natural barrier, preventing moisture loss and protecting against external irritants.

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- **Antimicrobial Properties:**
  Lauric acid, a key component of black soldier fly larvae lipids, exhibits antimicrobial and antibacterial properties, potentially helping to protect the skin from infections.
- **Sustainability:**
  Insect-derived lipids offer a more sustainable alternative to traditional plant or animal-based oils, as insects can be raised on organic waste, reducing land and water usage.

Specific Examples:

- **Black Soldier Fly Larvae (Hermetia illucens):**
  A significant source of fatty acids like lauric, myristic, palmitic, and oleic acids, which are beneficial for skin hydration and barrier function.
- **Lauric Acid:**
  Known for its antimicrobial and moisturizing properties, making it useful in soaps, creams, and other cosmetics.
- **Myristic Acid:**
  Used in cosmetic formulations for thickening and stabilizing emulsions, as well as restoring skin barrier properties.
- **Palmitic Acid:**
  Functions as an emulsifier and emollient in creams and lotions.
- **Oleic Acid:**
  Contributes to skin hydration and barrier function, and can be found in BSF larva oil.
  In summary, insect-derived lipids offer a promising avenue for developing sustainable and effective cosmetic products that enhance skin hydration and moisture retention. Their unique fatty acid profiles and potential antimicrobial properties make them a valuable ingredient for various skincare applications.

Lipids from insects in cosmetics and personal care products

Insect lipids offer an innovative and sustainable alternative to conventional cosmetic ingredients. Their diverse fatty acid profile and environmental benefits make them valuable for personal care products. Only one hurdle remains: overcoming consumer hesitation.

Image: Adobe Stock

Cochineal farming involves cultivating prickly pear cacti to host cochineal insects.

Current usage of insect-derived ingredients

Table: Uses of insect-derived products in cosmetics

Ingredient	Source Insect	Cosmetic Function	Reference
Carmine (E120)	*Dactylopius coccus* (cochineal insect)	Natural red pigment used in lipsticks, blushes, and makeup	Franco et al., 2021
Shellac	*Kerria lacca* (lac insect)	Film-forming agent in nail polishes, hair sprays, and mascara	Saidalavi et al., 2017
Chitosan	Derived from insect exoskeletons	Moisturizing and film-forming agent in skincare and haircare	Triunfo et al., 2021
Lauric & Myristic Acid	*Hermetia illucens* (black soldier fly)	Emollients used in soaps, cleansers, and creams	Verheyen et al., 2018
Mealworm Oil	*Tenebrio molitor* (mealworm)	Skin-conditioning agent in moisturizers and lotions	Ning et al., 2023
Cricket Extracts	*Acheta domesticus* (house cricket)	UV-protection and antioxidant properties in sunscreens	Kim et al., 2023

Market availability of insect-derived products in cosmetics

Insect-derived ingredients are increasingly present in the European cosmetics market, though their use remains relatively niche.

- Carmine (E120) is found in many commercial lipsticks, including brands such as MAC, NARS, and L'Oréal.
- Shellac (E904) is used in Sally Hansen and Revlon nail polishes for its glossy, long-lasting finish.
- Beeswax (E901) is a natural wax secreted by honeybees. It is widely used in cosmetics, skincare, haircare, and pharmaceuticals due to its emollient, protective, and thickening properties.
- Chitosan appears in high-end skincare and hair treatments, often labeled as a hydrating or film-forming agent.

- Lauric & myristic acid from black soldier fly are gaining traction in eco-friendly soap brands and natural skincare formulations.
- Cricket extracts are being explored in UV-protection and anti-aging creams, though still a niche market.

Societal perception and challenges

Consumer acceptance of insect-derived lipids remains a challenge. While environmentally conscious consumers appreciate their sustainability, cultural biases and the "yuck factor" hinder widespread adoption. Many individuals hesitate due to misconceptions regarding hygiene or are concerned about insect welfare, despite the eco-friendly benefits. Enhancing public perception through consumer education, certification, and branding efforts will be crucial.

Brands must adopt transparent marketing strategies, emphasizing the sustainability and dermatological benefits of insect-based ingredients. Beyond societal acceptance, regulatory hurdles must be addressed, as insect-derived ingredients need to comply with various cosmetic safety regulations. The European Union and other governing bodies are gradually adapting regulations to accommodate novel sources like insect lipids, but further standardization is required. Additionally, cosmetic manufacturers must work to overcome initial reluctance and integrate insect-derived ingredients into mainstream products through targeted collaborations and product innovations.

References

Akçay AA. 2024. The Use of Insect Pigment in Art Works. Insects 15;7:519. https://doi.org/10.3390/insects15070519

Almeida C et al. 2020. Bioactive compounds from Hermetia illucens larvae as natural ingredients for cosmetic application. Biomolecules 10;7:976. https://doi.org/10.3390/biom10070976

Ebenebe C et al. 2021. Arthropods in Cosmetics, Pharmaceuticals and Medicine: A Review. IntechOpen. https://www.intechopen.com/chapters/75778

Franco A et al. 2021. Lipids from insects in cosmetics and for personal care products. Insects 13;1:41. https://doi.org/10.3390/insects13010041

Franco A et al. 2022. Lipids from Insects in Cosmetics and for Personal Care Products. Insects 13;1:41. https://doi.org/10.3390/insects13010041

Halloran A et al. 2017. Life cycle assessment of cricket farming in north-eastern Thailand. Journal of cleaner production 156:83-94. https://doi.org/10.1016/j.jclepro.2017.04.017

Kim W et al. 2023. Research on the Value of Crickets as Ingredients for Cosmetics. IJHSR 5;3:125-130.https://doi.org/10.36838/v5i3.21

Kritsky G. 2024. A cultural history of insects in antiquity. Bloomsbury Publishing. ISBN: 9781350003217

Nejad HE & Nejad AE. 2013. Cochineal (Dactylopius coccus) as one of the most important insects in industrial dyeing. International journal of Advanced Biological and Biomedical Research 1;11:1302-1308. https://www.ijabbr.com/article_7910.html

Ngo HM & Moritaka M. 2021. Consumer attitudes and acceptance of insects as food and feed: a review.Journal of the Faculty of Agriculture Kyushu University 66;2:259-266. https://doi.org/10.15017/4486558

Ning B. et al. 2023. Insect bioactive compounds and their potential use in animal diets and medicine. Entomological research 53;11:429-443. https://doi.org/10.1111/1748-5967.12682

Saidalavi R et al. 2017. Analysis of lead and arsenic in cosmetics and assessment of students awareness about cosmetic toxicity. International Journal of Basic & Clinical Pharmacology 6;6: 1426–1430. https://doi.org/10.18203/2319-2003.ijbcp20172235

Salvia R & Falabella P 2021. Bioconverter insects: A good example of circular economy, the study case of Hermetia illucens. In An Introduction to the Circular Economy (pp. 261-280). Nova Science Publishers, Inc. ISBN: 978-1-53619-233-9

Triunfo M et al. 2021. Lipids from Insects in Cosmetics and for Personal Care Products. Cosmetics 8;2:40 https://doi.org/10.3390/cosmetics8020040

Verheyen GR et al. 2018. Insects as an Alternative Source for the Production of Fats for Cosmetics. J Cosmet Sci 69;3:187-202. https://doi.org/10.1002/ejlt.202200193 https://pubmed.ncbi.nlm.nih.gov/30052193/

Verheyen GR et al. 2023. The application of mealworm (Tenebrio molitor) oil in cosmetic formulations. European Journal of Lipid Science and Technology 125; 3:2200193. https://doi.org/10.1002/ejlt.202200193

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Survival and Dispersal of Microorganisms in Nature: Past to Present

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Microorganisms are fundamental to life on Earth, playing essential roles in ecosystems, agriculture, and human health. Their ability to endure extreme conditions and spread across diverse environments has made them key players in ecological and industrial processes. This article explores the mechanisms microorganisms use to survive—such as dormancy, spore formation, biofilm development, horizontal gene transfer, syntrophy, and metabolic adaptability—and the various ways they disperse through air, soil, water, and biological vectors. Additionally, human activities such as agriculture, urbanization, and industrial expansion have accelerated microbial movement, influencing global microbial dynamics. Recent advances in synthetic biology, AI-driven microbiome research, and nanotechnology are revolutionizing our understanding of microbial survival and dispersal. By harnessing microbial potential, we can develop innovative applications in medicine, agriculture, and environmental sustainability, ensuring their continued contribution to life on Earth.

Keywords: Survival, dispersal, microbes in nature

Microorganisms are the unseen architects of life on Earth, playing critical roles in ecosystems, agriculture, and human health. Their ability to survive in harsh conditions and disperse across vast distances is nothing short of remarkable. This article explores the fascinating strategies microorganisms employ to endure and spread and how modern environmental changes influence these mechanisms.

Modes of Survival: How Microorganisms Endure Harsh Conditions

Dormancy and Metabolic Slowdown

When conditions become unfavorable, many microorganisms enter a dormant state, drastically reducing their metabolic activity to conserve energy. This strategy is evident in bacteria that adopt a "viable but non-culturable" (VBNC) state, in which they remain alive but cannot be cultured in a lab. Fungi and archaea also employ similar tactics to survive nutrient-poor environments. Recent studies have identified specific genetic markers responsible for dormancy regulation, aiding in predicting microbial revival patterns. Synthetic biology advancements are exploring how dormancy genes can be manipulated for biotechnological applications, such as probiotics and biofertilizers. AI-based models are being developed to predict dormancy activation and its implications in microbial ecology.

Spore Formation: Time Capsules

Spore formation is a key survival strategy among microorganisms, allowing them to withstand extreme conditions. The different spore types and their roles in survival are detailed below:

Bacteria:

• **Endospores (Bacillus, Clostridium)**: Highly resistant to heat, chemicals, and radiation, endospores protect bacterial DNA during extreme stress.

• **Exospores (Streptomyces)**: Help bacteria survive nutrient deprivation by forming externally on the cell.

Fungi:

• **Conidia** (*Aspergillus*, *Penicillium*): Aid in rapid reproduction and dispersal.

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• **Sporangiospores** (*Rhizopus, Mucor*): Survive in soil and enable fungal propagation.

• **Chlamydospores** (*Fusarium, Candida*): Resist harsh conditions and enable long-term survival.

• **Ascospores** (*Saccharomyces*): Provide resistance to stress.

• **Basidiospores** (Mushrooms, rusts, smuts): Highly resistant to UV radiation and desiccation.

• **Zygospores** (*Rhizopus, Mucor*): Help fungi survive drought and cold conditions.

Protozoa:

• **Oocysts** (*Cryptosporidium*): Allow survival in water and soil.

• **Microsporidian Spores** (*Nosema*): Offer protection against environmental stressors.

Algae:

• **Akinetes** (*Anabaena, Nostoc*): Protect against desiccation and nutrient limitation.

• **Zoospores** (*Chlamydomonas*): Facilitate rapid colonization of new environments.

Studies have revealed that spores can reactivate after thousands of years, as seen in ancient permafrost samples. Climate change is altering the dormancy and reactivation patterns of microbial spores, potentially increasing the risk of crop diseases. Advances in nanotechnology are being used to develop coatings that can disrupt spore formation in pathogenic microbes. Genome editing (CRISPR) is being explored to control sporulation in beneficial microbes for agricultural applications. Deep-sea and space exploration studies are examining microbial spores' ability to survive in extraterrestrial environments.

Biofilm Formation: Strength in Numbers

Microorganisms often form biofilms which are structured communities encased in a self-produced extracellular matrix. These biofilms protect microbes from environmental stressors, such as desiccation, UV radiation, and antibiotics. In agriculture, biofilms enhance microbial survival on plant roots and leaf surfaces. Biofilms are now known to facilitate horizontal gene transfer among members, enhancing genetic diversity and adaptability, by enabling the spread of antibiotic resistance and metabolic genes. AI-driven imaging techniques are being used to study biofilm formation in real time. Research is underway to develop biofilm inhibitors to combat antibiotic-resistant infections in healthcare settings. Biofilm engineering is being explored for wastewater treatment and bioremediation applications.

Horizontal Gene Transfer (HGT): Sharing to care

Microorganisms in agricultural soils often engage in HGT, exchanging genetic material that confers traits like antibiotic resistance, pesticide degradation, and nutrient utilization. HGT is a major driver of antibiotic resistance and metabolic versatility. Enables rapid adaptation to environmental changes, such as antibiotic exposure or nutrient scarcity. Three primary mechanisms drive HGT:

• Transformation: A cell takes up free DNA from the environment.

• Transduction: A virus (bacteriophage) transfers DNA between cells.

• Conjugation: DNA is transferred directly from one cell to another through physical contact.

Mobile genetic elements (e.g., plasmids, transposons) are increasingly recognized as key players in HGT, even across distantly related species. The use of manure and wastewater in agriculture is contributing to the spread of antibiotic resistance genes through HGT. Scientists nowadays are developing gene-editing tools to control HGT and prevent the spread of antibiotic resistance genes. Environmental DNA (eDNA) analysis is being used to track HGT in real-time in different ecosystems. Bacteriophage therapy is being explored to target harmful gene transfer in microbial communities.

Syntrophy and Metabolic Cooperation

Syntrophy (also called cross-feeding) is a type of symbiosis where two or more microbial species work together to degrade complex substrates or survive in nutrient-limited environments. Microorganisms engage in metabolic partnerships where one species' waste products serve as nutrients for another. Many microorganisms form mutualistic relationships with plants, enhancing their survival. For example, nitrogen-fixing bacteria (e.g., Rhizobium) and mycorrhizal fungi improve plant nutrient uptake in exchange for carbohydrates. Methanogenic archaea and sulfate-reducing bacteria cooperate to degrade organic matter in anaerobic environments. Synthetic microbial consortia are being designed to enhance bioremediation and bioenergy production. AI-based metabolic modeling is being used to optimize microbial partnerships for industrial applications.

Utilization of Alternative Energy Sources

Some microbes can survive in nutrient-poor environments by oxidizing inorganic compounds like sulfur, iron, and nitrogen. Anaerobic respiration and fermentation also help microbes endure low-oxygen conditions.

Production of Protective Compounds

Microbes produce osmoprotectants such as trehalose and glycine betaine to combat dehydration. Some also secrete antibiotics to outcompete other microbes.

CRISPR-Cas Systems: The Microbial Immune System

Microbes use CRISPR-Cas systems (Clustered Regularly Interspaced Short Palindromic Repeats and CRISPR-associated proteins) to defend against viruses and plasmids by targeting specific DNA sequences. This system is now being harnessed for gene editing in biotechnology.

Survival in Extreme Conditions

Microorganisms can sometimes thrive in extreme environments like: halophiles in high-salt conditions, thermophiles in heat, psychrophiles in cold, acidophiles in acidic environments, and alkaliphiles in basic conditions. Their adaptability showcases the vast potential of microbial life.

Modes of Dispersal: How Microorganisms Travel the World

Microbial dispersal methods can be broadly classified into physical methods (airborne, soilborne and waterborne), biological methods (animal vectors, plant-mediated) and anthropogenic methods.

Airborne Dispersal

Microorganisms can travel long distances via aerosols, dust, and water droplets. Fungal spores, such as those from Aspergillus and Penicillium, and bacterial cells like Pseudomonas can be carried by wind. Atmospheric rivers and storms have been shown to transport microbes across continents, influencing global microbial biogeography. Spores of Bacillus and Clostridium resist UV radiation and desiccation, allowing long-distance aerial dispersal. Airborne pathogen monitoring systems are being developed using machine learning and remote sensing.

Soil and Waterborne Dispersal

Microbes spread through soil erosion, runoff, and irrigation as well as through water film covering the soil particles. Phytophthora, a pathogenic fungus, disperses through contaminated water. Raindrops cause soil splash, propelling microbes into the air or relocating them in surface soil. Marine viruses and bacteria are dispersed by ocean currents, contributing to the global "viral shunt" that regulates nutrient cycling. Environmental DNA sequencing is being used to track microbial dispersal in soil and water systems. As an application of this method of dispersion microbial probiotics are being introduced to soil and water ecosystems to enhance bioremediation.

Animal Vectors

Insects, birds, and mammals act as carriers for microorganisms. For example, bees and other pollinators disperse beneficial microbes like Lactobacillus and Bacillus species, which can enhance plant health. Conversely, insects like aphids and whiteflies spread viral and bacterial pathogens

Microbial Hitchhiking

Microbes attach to larger particles, such as dust or microplastics, facilitating long-distance dispersal. Studies suggest that microplastics serve as vehicles for antibiotic-resistant bacteria.

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Plant-Mediated Dispersal

Microorganisms can move within and between plants through root exudates, vascular systems, and pollen. In rhizosphere interactions, root exudates (sugars, amino acids) attract microbial colonizers, facilitating movement via chemotaxis. Another method of plant mediated dispersal is through seed dispersal. Endophytic bacteria and fungi are dispersed when seeds germinate, influencing plant-microbe symbiosis

Human Activities: Accelerating Microbial Dispersal

Agricultural Practices

Plowing and tillage disturb microbial communities by redistributing soil bacteria and fungi, while the application of compost and manure introduces diverse microbial species, enriching soil biodiversity. Irrigation and flooding further influence microbial distribution by mobilizing bacteria through water flow, reshaping microbial populations across different regions. Additionally, the global trade of agricultural products has facilitated the spread of invasive pathogens, such as Fusarium oxysporum, the fungus responsible for Panama disease in banana plantations, posing significant threats to crop health and food security.

Industrial and Urban Activities

Construction and mining activities disrupt soil structure, bringing deep-seated microbes to the surface and altering their natural habitats. The application of wastewater and biosolids further impacts microbial communities by introducing industrial and human-associated microbes into the soil, potentially affecting ecosystem balance. Additionally, genetically engineered microbes are increasingly being introduced as biofertilizers or biocontrol agents, enhancing plant growth and soil health while influencing microbial interactions in agricultural environments.

Conclusion

Microorganisms are not merely passive inhabitants of ecosystems; they are dynamic, adaptive, and deeply influential. Their resilience and dispersal mechanisms shape biodiversity, influence agriculture, and impact human health. As climate change and human activities continue to reshape microbial landscapes, understanding their survival and dispersal strategies is crucial. By harnessing microbial potential, we can develop sustainable solutions in medicine, agriculture, and environmental conservation, ensuring that these unseen architects continue to support life on Earth.

References

1. Custer, G. F., Bresciani, L., and Dini-Andreote, F. 2022. Ecological and Evolutionary Implications of Microbial Dispersal. Frontiers Microbiol. 13. https://doi.org/10.3389/fmicb.2022.855859

2. Smith, D. J., Griffin, D. W., and Jaffe, D. A. 2011. The high life: Transport of microbes in the atmosphere. Eos, Transactions Am. Geophysic.l Union, 92(30), 249–250. https://doi.org/10.1029/2011EO300001

3. Snyder, A. B., Biango-Daniels, M. N., Hodge, K. T., and Worobo, R. W. 2019. Nature Abhors a Vacuum: Highly Diverse Mechanisms Enable Spoilage Fungi to Disperse, Survive, and Propagate in Commercially Processed and Preserved Foods. Comprehensive Rev. Food Sci.Food Safety, 18(1), 286–304. https://doi.org/10.1111/1541-4337.12403

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"BRIDGING THE GAP: THE ROLE OF EXTENSION EDUCATION IN EMPOWERING AGRICULTURAL STUDENTS"

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This article emphasizes the important role of extension education in acting as a bridge between theory and practice in agriculture. It emphasizes the role of extension education in empowering agricultural students. The article criticizes agricultural education for its lack of practical experience for students in its educational programs, making them unprepared to solve real-world challenges after graduation. It also describes the broad scope of extension education, including the use of exposure visits, RAWE, farmer-scientist interactions and ICT tools, along with the challenges including infrastructure challenges, lack of awareness and limited integration of extension in the curriculum. Moving forward, call for curriculum redesigning and a strong linkage between farmers and the university, and utilization of various digital platforms is necessitated.

Introduction

Agricultural education plays a vital role in developing skilled human resources equipped with practical knowledge to support the sector's growth. Its core focus is hands-on learning, which provides realistic field experience. However, students often lack practical skills due to challenges like outdated teaching methods, limited funding, insufficient practical exposure, and low engagement from both teachers and learners (Everest *et al.,* 2024). As a result, many graduates struggle to apply their knowledge in real-life agricultural settings or pursue self-reliant ventures (Amadi & Adejoh, 2020). Integrating practical learning with theoretical education is essential to equip students with problem-solving abilities, better job prospects, and real-world competencies. Extension education plays a crucial role in this integration, acting as a bridge between classroom concepts and field-level application.

What is extension education?

Extension education is a type of education which is designed to extend the skills and knowledge of individuals beyond the traditional classroom settings. The extension system was born when an extensive gap between research findings and knowledge among farmers was reported. These are generally provided by on-field visits, demonstrations, online courses, workshops, seminars, conferences etc. It facilitates the utilization of resources by people effectively with little government assistance in the developmental process. Its aim is to increase the ability of the rural people in adopting modern agricultural practices.

The principles of extension education include:

- Extension education must be relevant to the needs of its target audience.
- Extension education must improve the quality of life and have a positive impact on the lives of its participants.
- Extension education must be efficient in terms of its use of resources i.e. programs must be designed to use resources efficiently to achieve the desired impact.
- Extension education must produce sufficient revenue to cover costs and generate profit, in short it should be economically viable.
- Extension education must be accountable to its target audience, funding sources, and other stakeholders. Programs must be designed to meet the expectations of those who support and fund them.

Why extension matters to agricultural students?

Agricultural extension education offers students real-world applications of classroom teaching experiences and problem-solving. Extension education builds skills like communication, leadership, and decision-making through contact with rural people. Practical activities, such as field visits, public demonstrations, and participatory learning, also provide the opportunity for mentorship and hands-on learning experience. Practical contact with farmers provides students with the opportunity to build confidence and improve interpersonal relations. Overall, extension education narrows the gap from land to lab and gives students the chance to apply research to real-world agricultural solutions.

Extension methods benefitting students

1. **Exposure visits and field trips:**

Exposure visits and farm field trips promote hands-on-learning opportunities for students. Students get to experience learning beyond the classroom boundaries, getting proper practical knowledge by interact with nature, and observing seasonal crops in real-life environment.

2. **Rural Agricultural Work Experience (RAWE):**

The Rural Agricultural Work Experience Program (RAWE) was introduced in the UG curriculum as per the recommendation of the Randhawa Committee during the year 1995-96. During the RAWE programme, the final year agricultural students live alongside farmers in their villages to study about the social, economic and political structure of the villages.

RAWE helps the students primarily to understand the rural situations, status of agricultural technologies adopted by farmers, prioritize the farmer's problems and to develop skills and attitude of working with farm families for overall development in rural area.

3. **Farmer-scientist interaction:**

Farmer-scientist interactions provides great learning opportunities for agricultural graduates as by observing the exchanges between the farmers and the scientists, they get to know how farmers describe their real life problems and how scientists translate the technical solutions to practical advice in order to help the farmers.

4. **Use of ICT tools and e-extension platforms:**

ICT and e-extension platforms can transform agricultural extension by enabling students to share information digitally through videos, social media, and mobile apps, reaching wider farmer audiences.

Engaging with these platforms equips students with essential digital skills, preparing them for the evolving technological landscape in agriculture.

Success story

As part of their Rural Agricultural Work Experience (RAWE) program in Sathyamangalam, Erode district of Tamil Nadu, students of Tamil Nadu Agricultural University availed themselves of extensive first-hand learning through direct interaction with agriculture experts and native farmers. Mr. Shankar, in his capacity as a Seed Certification Officer, gave comprehensive information on the operations of seed processing units, seed inspection, and seed testing laboratories, enhancing students' knowledge of seed quality management. Mr. Venkatesan provided information regarding seed processing equipment, whereas Mr. Sathish Kumar discussed the process of manufacturing biofertilizers, mother culture preparation, and operation of the production machines. The students also performed a practical demonstration with yellow sticky traps in controlling the whitefly infestation on jasmine fields in Thaandampalayam. By installing traps in the field of Mr. R.J. Shivaram, they demonstrated an efficient, eco-friendly method of pest control. The demo promoted active participation by the farmers and facilitated useful discussion with the Assistant Director of Horticulture, Mr. Palanisamy, who shared additional advice on managing pests. Watching the whiteflies get caught reaffirmed the learning of the students and underscored the effectiveness of combining extension education with actual field concerns. With these experiences, RAWE helped students apply classroom theory to the practical world, enhance confidence in communicating with farmers, and gain problem-solving skills essential for their future work in agriculture.

Conclusion

Extension education is not just an add-on to agricultural learning—it is a necessity. It equips students with the operational skills, confidence, and experience necessary to be problem-solvers and change agents in the agricultural industry. When students have education in extension, it connects their learning with the field, it's a way to prepare them not only ready for jobs, but also to be change agents in rural development and food security professions. As agriculture continues to respond to global challenges and resource scarcity to meet increasing production demands, it is critical that institutions articulate systemic investment into structured and innovative extension programming. Investing in these important roles will only enhance the sustainability of agricultural education and ultimately create a generation of agri-professionals who lead with knowledge, compassion, and purpose.

References

- Amadi, N. S., & Adejoh, G. (2020). Strategies for re-orienting agricultural education towards hands on experience in Rivers State Universities. *Advance Research and Reviews*, 5(3), 64-73.
- Arundhathi, C., Ganesamoorthi, S., Shivalingaiah, Y. N., Latha, H. S., & Kumar, T. M. (2024). Constraints of Student READY Programme in State Agricultural Universities. *Journal of Scientific Research and Reports*, 30(5), 78-81. https://doi.org/10.9734/jsrr/2024/v30i51923
- Everest, T., Ssemakula, E., & Nuwemuhwezi, G. (2024). Relevancy of Modern Agriculture Education on Students' Farming Practical Skills in Secondary Schools of Kabujogera Town Council, Kitagwenda District. *Teacher Education and Curriculum Studies*, *9*(1), 12-20.
- Singh, S. K., Singh, A. K., & Maji, S. (2021). Constraints faced by the students in the usage of ICT initiatives in agricultural education. *Indian Journal of Extension Education*, 57(1), 114-117.
- Sulaiman, R. V., Sreeram, V., Onima, V. T., & Mittal, N. (2018). *Agricultural extension curricula in India: Is it relevant to changing times*. AESA Working Paper 2018-004, Hyderabad, India: CRISP. https://doi.org/10.13140/RG.2.2.12658.12489

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FPO: Power in Unity-Transforming farmers into Agri-Entrepreneurs

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FPOs are groups of farmers who come together to work as a team, making it easier to get good prices, reduce costs, and use modern farming methods. This article explains how Farmer Producer Organizations (FPOs) are helping farmers in India overcome many problems like small landholdings, lack of market access, high input costs, and limited technology. The article also discusses government support, successful examples from different states, and the challenges FPOs face. It highlights the importance of FPOs as powerful tools to turn farmers into agri-entrepreneurs and build a stronger rural economy in India.

Introduction

Ningzanla Keishing, a farmer from Bungpa Khunou in Manipur's Kamjong District, transformed her farming journey after joining a Farmer Producer Organization (FPO). Previously, she faced challenges like poor seed quality, lack of pest control knowledge, and limited market access, resulting in low productivity and poor returns. Her turning point came through the Central Sector Scheme of FPO formation, introduced by the Switch ON Foundation. After joining as a Farmer Interest Group (FIG) member, she received training in organic farming, manure preparation, and pest control. This knowledge enhanced her confidence and skills, enabling her to expand her cultivation area from 10,000 sq. ft. to 30,000 sq. ft. Beyond personal growth, Ningzanla now shares her knowledge with fellow farmers, uplifting her entire community. India's agriculture sector continues to grapple with issues like fragmented landholdings, limited credit, and low adoption of modern technologies. FPOs offer a collective solution to these individual struggles by improving market access, enabling the adoption of agri-tech, acting as financial intermediaries, and promoting women's participation in farming. Collaborations with agri-tech startups have introduced innovations such as drone spraying, real-time soil monitoring, and climate-resilient farming practices. As India aims for agricultural self-sufficiency by 2047, FPOs are crucial in building a sustainable, inclusive, and prosperous rural economy.

What is FPO?

FPO (Farmer Producer Organization) is a registered and legal entity formed by farmers, usually small and marginal, to work collectively for better income and livelihood. It can be registered as Producer Companies, Co-operatives or Societies. The ownership control of the FPOs is always with its members and management is through the representatives of the members. It is an organization of the producers, by the producers and for the producers (APEDA, n.d.).It deals with business activities related to primary produce and a part of profit earned is shared amongst the producers. Surplus profit is added to its owned funds for business expansion.

Why do Farmers need FPOs?

India's agriculture sector comprises a diverse mix of small, medium, and large farmers scattered across the country, making it difficult to manage and support effectively. Farmers often struggle with fragmented landholdings, weak bargaining power, high input costs, poor market access, and exploitation by middlemen. In addition, they face barriers in accessing credit, modern technologies, and essential infrastructure. This is where Farmer Producer Organizations (FPOs) play a vital role. FPOs organize farmers in a specific region into a collective, enabling better division of labor, focused production, easier coordination, and greater visibility. Acting as a bridge between farmers and stakeholders—such as government agencies, financial institutions, and the private sector—FPOs help streamline operations and improve service delivery. Farmers need FPOs to overcome these persistent challenges, and the following points highlight the key reasons:

- **Small and fragmented land holdings**: Indian agriculture is largely dominated by small and fragmented landholdings, which lead to operational inefficiencies and increased costs per unit of output, ultimately reducing farmers' income. According to the Agriculture Census of India, over 85% of operational holdings are smaller than 2 hectares (Choudhary, 2024).This fragmentation has worsened over time due to population growth, inheritance practices, and land ceiling laws. Small plots are difficult to mechanize, limiting the use of modern technologies and machinery, which are essential for enhancing productivity. As a result, farmers on fragmented lands often struggle to adopt crop rotation, land consolidation, and technology-driven farming methods.

  Moreover, smallholders have less bargaining power, making it harder for them to access markets or secure fair prices for their produce. Therefore, fragmented landholding remains a major structural challenge, restricting the growth and sustainability of Indian agriculture
- **Limited access to market and weak bargaining power**: Farmers often face a weak bargaining position due to limited access to markets, lack of market information, and insufficient capital. This vulnerability is exploited by middlemen, who offer unfairly low prices and dominate the supply chain. The situation worsens for farmers dealing with perishable produce, as urgency compels them to sell at any available rate. Additionally, limited access to formal credit forces many small farmers to depend on middlemen for financial support, trapping them in a cycle of debt and dependency. This lack of bargaining power and market access significantly reduces farmers' profitability and adds to their ongoing challenges.
- **High input costs:** Rising input costs significantly reduce farm profitability and discourage increased production, contributing to food insecurity and low income for farmers. Essential inputs such as seeds, fertilizers, fuel, and other agrochemicals have become increasingly expensive, making it harder for farmers to sustain their livelihoods. In addition, inflation, high interest rates, and global supply chain disruptions—triggered by events like the Russia-Ukraine war and bottlenecks at the Panama and Suez Canals—have further driven up production costs while farmers continue to receive low commodity prices. This growing disparity between input expenses and farm income highlights the urgent need to factor such economic pressures into future agricultural planning and support mechanisms (Loy & Biram, 2024).
- **Difficulty in accessing technology and infrastructure:** The "digital divide" is an issue in agriculture where some farmers do not have access to, or engage with, technologies in the way other farmers do (Hennessy *et al.,* 2016).Insufficient network coverage, poor electricity and transportation in rural areas are amongst the many problems the rural farming community faces. These issues forces them to have limited access to the essential technology and infrastructures that has been evolving in todays world, hindering them to make progress in their farming ways and ultimately stopping them for earning a better living.

In order to deal with such issues, FPOs help in collectivization of such small, marginal and landless farmers, which helps them with a better management system for increasing their productivity. Hence, FPOs are a great need for the farmers at the moment.

Benefits of FPOs-Power of Collectivization

FPO turns out to be extremely beneficial to farming community, which can be as such:

- ✓ The FPOs provide training facilities for the farmer members, managers, elected representatives and employees to contribute to the FPOs development collectively.
- ✓ The FPOs can provide better quality and low-cost inputs to farmer members such as machinery, pesticides, fertilizers etc. They facilitate collective input purchase at lower prices.
- ✓ FPOs involve women farmers in decision making which will increases inclusiveness in agricultural sector.
- ✓ Joint training on Good Agricultural Practices (GAP), extension services and access to modern technology are provided by the FPOs.
- ✓ The FPOs can help farmers in competing with large corporate enterprises in bargaining, where they can negotiate as a group and help small farmers in both output and input markets.
- ✓ They facilitate bulk selling to markets or buyers at better prices.
- ✓ FPOs also provide opportunities for value addition, branding, processing and joint storage facilities which reduce post-harvest losses.
- ✓ Access to institutional credit against shock, without collateral by virtue of joint liability implicit in the FPO framework.
- ✓ FPOs provide custom hiring services in terms of equipment like tractors, harvesters, tillers etc. which helps in saving production and cultivation costs.
- ✓ FPO operates common facilities for primary and secondary processing and direct sale, which enables. Higher value of accruals to farmer.

How FPOs work-simple overview

FPO is an organization of the producers, specifically the primary producers. FPOs can be formed by 100 plus farmers (minimum) comprising of all primary producers residing in the relevant geography, and producing the same or similar produce, for which the FPO has been formed. FPOs are run democratically by a Board of Directors elected from the members. Membership in such an organization is voluntary and the procedure for obtaining FPO membership depends on the bye-laws of the FPO. All members enjoy equal rights-be it the founder members or the members who have joined later. A primary producer can become member of a FPO by submitting an application and a nominal membership fee. Producer Organisations can be registered under any of the following legal provisions (APEDA, n.d.):

- ❖ Cooperative Societies Act/ Autonomous or Mutually Aided Cooperative Societies Act of the respective State
- ❖ Multi-State Cooperative Society Act, 2002
- ❖ Producer Company under Section 581(C) of Indian Companies Act, 1956, as amended in 2013
- ❖ Section 25 Company of Indian Companies Act, 1956, as amended as Section 8 in 2013
- ❖ Societies registered under Society Registration Act, 1860
- ❖ Public Trusts registered under Indian Trusts Act, 1882

The Government of India has strongly supported Farmer Producer Organizations (FPOs) to empower farmers and boost agricultural growth. Under the Central Sector Scheme launched in February 2020 by Prime Minister Narendra Modi, the goal is to form and promote 10,000 FPOs by 2027–28. So far, over 30 lakh farmers, including 40% women, have joined FPOs engaged in agri-businesses worth thousands of crores (Press Information Bureau, 2025). Equity grants of ₹254.4 crore have been disbursed to 4,761 FPOs, and credit guarantee cover worth ₹453 crore has been extended to 1,900 FPOs. The 10,000th FPO was recently launched in Khagaria, Bihar, focusing on maize, banana, and paddy. Since 2011, the government has promoted FPOs through NABARD, SFAC, NGOs, and state agencies. Budget 2018–19 introduced a five-year tax exemption, while Budget 2019–20 reinforced the 10,000 FPO target. Support includes equity grants up to ₹10 lakh and credit guarantee cover for loans up to ₹1 crore. FPOs are also promoted under the 'One District One Product' model to enhance market access through product specialization. Ministries such as Agriculture, Food Processing, MSME, Fisheries, and APEDA work collaboratively to support FPOs across the country.

Success Stories

Tylli Deimaia Joint Farming Cooperative Society: Tylli Deimaia Joint Farming Cooperative Society, an FPO based in Laskein, Meghalaya, comprises 104 shareholders along with several farmers receiving indirect support through its initiatives. The FPO provides training in organic farming, piggery management, lactic acid bacteria use, indigenous microorganisms, rechargeable trench techniques, and other thematic areas. It also links farmers with government schemes such as the Piggery Mission and Mission Lakadong (Turmeric), while promoting modern farming techniques. By cultivating crops like turmeric, ginger, maize, rice, potato, and tomato, farmers have significantly improved their profitability. Recently, the FPO procured a turmeric washer and dryer under the Lakadong Mission and a polyhouse from Bethany Society, Shillong. In addition to technical support, the FPO offers guidance on entrepreneurship, connects farmers with government departments, and builds partnerships with local agencies. The success of this FPO highlights the strength of collective farming in empowering smallholders and enhancing rural livelihoods.

Sahyadri Farms (Maharashtra): Sahyadri Farms is one of India's leading Farmer Producer Companies who started their journey in 2010 with just eleven marginal farmers owning table grape plantations. Their technology-led interventions ensures reduced production costs and improved fresh produce quality leading to better rates to farmers. It a 100% farmer-owned company impacting more than 18,000 registered farmers covering 31,000 acres and 9 crops.

Challenges faced by FPOs

- **Lack of awareness among farmers:** Lack of awareness among farmers about FPOs significantly hinders their growth and success. The farmers who are unaware about these organizations are less likely to join, participate actively, or understand the benefits of FPOs, leading to lower membership, reduced access to resources, and ineffective collective action.
- **Inadequate training and management skills:** Inadequate training may limit the farmers from getting knowledge about new and improved agricultural practices and digital tools, while inadequate management skills might lower their sound decision making power. This might limit the ability of FPOs to function properly and achieve their goals.
- **Struggles in market linkage and branding:** FPOs encounter a multitude of challenges in their marketing their produce, which significantly impact their ability to maximize returns for their members. Their operation at a small scale, serving localized and often marginalized communities poses a significant constraint when it comes to accessing broader and more lucrative markets, which can hinder FPOs' ability to obtain favorable prices for their produce. FPOs also often lack the resources and infrastructure necessary to maintain the quality standards of their produce, resulting in a diminished ability to attract buyers and consumers who prioritize quality.
- **Limited infrastructure and capital:** FPOs often struggle to access affordable credit and financial services, which are essential for investing in agricultural inputs, infrastructure development, and value addition activities, which serves as a roadblock for their success.
- **Limited Capacity**: Limited human resources, technical expertise, and management skills, among the FPOs also

hinder their effective functioning and sustainability.

- **Regulatory Issues**: FPOs may also encounter regulatory barriers and complex legal requirements, which obstruct their registration, operation, and access to government schemes and support programs.

Way Forward

To fully unlock the potential of Farmer Producer Organizations (FPOs) in transforming Indian agriculture, several strategic measures are essential. These include conducting widespread awareness campaigns and expanding capacity-building efforts through NGOs and government agencies. Strengthening market linkages via dedicated digital platforms can connect FPOs directly with buyers and exporters. Promoting regional branding can help showcase unique local produce. Access to improved credit guarantee schemes, infrastructure, and modern technologies must be ensured. Encouraging the active participation of youth and women will enhance inclusiveness. Collaborations with agri-startups and corporate buyers can further boost innovation and market access. By addressing these areas, FPOs can grow from basic farmer groups into dynamic engines of rural economic transformation.

Conclusion

Farmer Producer Organizations (FPOs) serve as a crucial bridge between subsistence farming and commercial agriculture in India. By organizing individual farmers into collectives, FPOs address key challenges such as fragmented landholdings, weak bargaining power, limited technology access, and market vulnerability. They demonstrate how collective action can drive meaningful change in rural economies, empowering farmers to become confident agri-entrepreneurs capable of competing in modern markets. The FPO model proves that collaboration can overcome individual limitations and build resilient, profitable enterprises that uplift entire communities. In essence, FPOs are not just farmer groups—they are catalysts for rural transformation. Strengthening the FPO movement is vital for securing a sustainable and inclusive agricultural future.

References

Acharya (2024). Farmer Producer Organization (FPO). https://cleartax.in/s/fpo-farmer-producer-organization-scheme#h3

APEDA (n.d.). Farmers Producer Organisation. https://farmerconnect.apeda.gov.in/Home/ForGroups?PaccessID=1.

Choudhary (2024). The Challenge of Fragmented Land Holdings in Indian Agriculture. https://www.linkedin.com/pulse/challenge-fragmented-land-holdings-indian-agriculture-chaudhary-zcilf

Hennessy, T., Läpple, D., & Moran, B. (2016). The digital divide in farming: a problem of access or engagement?. *Applied Economic Perspectives and Policy*, 38(3), 474-491.

Loy and Biram (2024). Farmers pay higher input costs while receiving lower commodity prices. https://www.farmprogress.com/farm-business/farmers-pay-higher-input-costs-while-receiving-lower-commodity-prices

Press Information Bureau (2025). 10,000 FPOs Achieved under Government’s Flagship Scheme-A Step Towards Atmnirbhar Krishi. https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2106913.

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"Farming Smarter: The Critical Role of Training in Modern Agriculture"

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With our constantly evolving surroundings, economy, and technology, agricultural training is now more important than ever for motivating farmers to adapt and innovate. This article analyzes the multifaceted effects of training in contemporary agriculture, and how it helps close gaps in knowledge, encourages sustainability and responsible agri-entrepreneurship, as well as aids in digital literacy. Furthermore, the article caters to the need for all-inclusive training aimed at women, youth, and smallholder farmers while addressing underlying issues like why there is gender discrimination as well as barriers to access and net lacking proper follow up. By evaluating the role of government institutions and NGOs, as well as the local population, this article presents an integrated strategy towards fostering self-sustaining and self-educated farming communities.

Introduction

The life of Farmer Nikki Kumari from Ranchi's Bero Block exemplifies the success stories that agricultural education and training create. After being stuck with low returns from her 6-7 acre farm due to traditional methods of farming, enrolling into the Millionaire Farmer Development Programme changed her fortunes completely. Her income increased from Rs 6-5 lakh a season, to Rs 12-13 lakh after the training taught her modern skills like drip irrigation, multi-tier farming, and even grafting that increased the standard of living of her family.

As agriculture faces various challenges from climate change and rapidly shifting market demands, the importance of such training programs becomes even more critical. Today's farmers must take into account not only environmental uncertainties but also evolving consumer preferences, changing supply chains, and fluctuating commodity prices. Modern agricultural training helps the farmers to acquire the market intelligence and adaptability needed to identify profitable opportunities and pivot their operations accordingly. The most effective agricultural training recognizes shared values between traditional and modern approaches. Programs that honor ancestral farming knowledge while introducing technologies like precision agriculture create powerful synergies. For instance, combining traditional crop rotation principles with modern management tools allows farmers to maintain soil health while optimizing yields for current market conditions; diversified crop rotation (DCR) improves the efficiency of farming systems all over the world. It has the potentiality to improve soil condition and boost system productivity (Shah *et al.*, 2021).

Farmer Nikki Kumari

Nikki's who is now an inspiration for many farmers from surrounding villages—

demonstrates how training programs creates ripple effects throughout rural communities. With ever increasing climate challenges, change in market dynamics, and food security concerns, investing in agricultural training programs becomes extremely important: cultivating not just stronger crops, but more resilient farming communities who can thrive amid both environmental and economic change.

Why training is crucial for farmers today?

Farmers today face numerous challenges that directly affect their productivity and livelihoods. Key issues include poor transportation, inefficient irrigation, limited access to quality inputs, and insufficient capital, which hinder both crop production and market access (Raghuvanshi, 2014). Environmental concerns like soil erosion and urbanization further aggravate the situation, while a lack of technical knowledge on fertilizer and pesticide use creates additional barriers. In this context, agricultural training has become essential. Modern training programs bridge knowledge and skill gaps by educating farmers on soil testing, crop selection, pest control, water conservation, and market analysis. These programs use diverse methods such as classroom teaching, field demonstrations, exposure visits, and peer learning to enhance farmers' decision-making and adaptability. Entrepreneurship development is also a key component, equipping farmers with financial literacy, business planning, and marketing skills. This empowers them to run sustainable agri-businesses and respond effectively to changing market and environmental conditions. Furthermore, community-based training encourages collaboration, leading to the formation of cooperatives that foster shared learning, support, and resilience. Overall, well-structured training enhances individual capabilities while strengthening rural communities for long-term agricultural and economic sustainability.

What kind of training do farmers need?

- **Technical training**: Farmers need training in modern agricultural techniques such as automated irrigation, precision farming, and high-yield crop varieties. They also learn to operate machinery like tractors and harvesters efficiently. Additionally, training includes sustainable methods like organic farming and integrated pest management, helping farmers boost productivity and adapt to new challenges.
- **Agri-entrepreneurship training:** Entrepreneurial skills are essential for turning farming into a profitable venture. Training focuses on business management, value addition, branding, and marketing. With support from extension workers, farmers are guided to build and manage agribusinesses, improving their income and market reach.
- **Digital literacy:** In the digital era, farmers benefit from using tools like GPS, mobile apps, and online platforms. Digital literacy training helps them access market data, weather updates, online sales platforms, financial services, and government schemes. It also enables record-keeping, online learning, and adoption of climate-smart practices.
- **Sustainable practices:** Training in sustainable agriculture teaches eco-friendly practices such as crop rotation, composting, and natural pest control. It promotes soil health, water conservation, and reduced chemical use. This helps farmers shift from conventional to sustainable farming for long-term productivity and environmental protection.

Anmol Mahila Dudh Samiti: Empowering Women Through Dairy Entrepreneurship

A group of women from modest backgrounds in Amritpur Kalan village near Karnal came together to form the "Anmol Mahila Dudh Samiti," becoming a symbol of empowerment and inspiration for other women (National Institute of Agricultural Extension Management,2018).With encouragement from the Arpana Trust, which helped mobilize and support them, the women decided to start a milk-based business, recognizing two key opportunities: the village's high milk production and the low prices local farmers were receiving. They began by collecting just 20 litres of milk and gradually expanded to 500 litres per day. Offering fairer prices—Rs. 20 per litre for cow milk when the market rate was only Rs. 12—they created a profitable system. They sell cow milk at Rs. 28/litre and buffalo milk at Rs. 45/litre, supplying to places like NDRI hostels, marriage venues, hotels, and sweet shops in Karnal. Demand for their pure, high-quality products remains strong, especially during festivals like Diwali when they also sell milk-based sweets. Each member now earns around Rs. 5,000–6,000 per month, all while managing household duties. The women divide tasks like milk collection, order handling, book-keeping, and value addition by working in shifts while the marketing and sales is handled by the group leader, Ms. Kamalesh. In the initial phases, they often faced challenges in the form of restrictions from their family and community, but their hardwork and sheer determination helped them overcome these hurdles. Today, they stand financially independent and socially empowered. A huge part of their success goes to the three – month training programme conducted by NDRI, teaching them to make paneer, curd, ghee, and khoya while also providing technical support for the preparation of these items. With a Rs. 1.5 lakh loan from the Arpana Trust, they purchased essential equipment like a weighing machine, fat separator, fridge, and milk cans. Now, the group produces according to demand, carefully planning quantities based on orders. The group also plans to begin packaging their dairy products to multiply their profits. Their success has not only improved their savings and family status but also enabled them to invest in their children's education. This group today stands as a role model for women's entrepreneurship and empowerment. The group has given significant credit for their achievement to the training and technical guidance provided by NDRI, which helped them gain the skills and confidence needed to build a successful value-added dairy enterprise.

Role of Government and Institutions

In Amritpur Kalan village near Karnal, a group of women from modest backgrounds formed the Anmol Mahila Dudh Samiti, emerging as a beacon of empowerment and self-reliance (National Institute of Agricultural Extension Management, 2018). With support from the Arpana Trust, the women capitalized on two local opportunities: abundant milk production and low returns for dairy farmers. Starting with just 20 litres of milk, they gradually scaled up to 500 litres per day. By offering fair procurement rates—Rs. 20/litre when the market offered only Rs. 12—they established a profitable system. Their milk is sold at Rs. 28/litre (cow) and Rs. 45/litre (buffalo), with regular buyers including NDRI hostels, hotels, and sweet shops in Karnal. The group's products, especially during festivals like Diwali, enjoy strong demand. Each member now earns Rs. 5,000–6,000 per month while continuing household responsibilities. Work is divided efficiently: milk collection, processing, bookkeeping, and value addition are handled in shifts, while marketing is led by Ms. Kamalesh. Despite facing societal and familial resistance initially, their perseverance enabled them to overcome challenges and achieve financial independence. A major turning point was the three-month training program by NDRI, where they learned to make paneer, curd, ghee, and khoya. Technical support and a Rs. 1.5 lakh loan from Arpana Trust helped them purchase essential equipment like a fat separator, fridge, and milk cans. They now produce based on order demand and plan to begin packaging their dairy products to boost profits further. The group credits their success to the training and guidance from NDRI, which equipped them with both skills and confidence. Today, they not only contribute to household income and invest in their children's education but also serve as a role model for rural women aspiring to become entrepreneurs.

1. **Limited accessibility in remote areas:**

- The farmers' ability to attend training programs or access digital learning platforms is restricted by the lack of basic infrastructure such as proper road connectivity, transportation and reliable electricity and internet connectivity (Raghuvanshi,2014).
- Training centers are often located far from these communities, hence farmers find it costly and challenging to make frequent trips to the training facilities.
- In addition, erratic power supply and poor internet coverage hampers the use of online training tools, webinars, and mobile applications that could otherwise provide valuable information and updates.

2. **Literacy/language barriers:**

- Many farmers, particularly the older individuals or those from marginalized community have very limited access to formal education. This serves as an obstacle for them as they find it difficult to comprehend the technical terms, complex agricultural concepts, written materials, charts, or digital content provided to them in the training programs especially when they are not available in their local languages (Gupta et al.,2023). This can lead to low participation of farmers, as they feel left out from the learning process which ultimately results in poor adoption of new practices by the farmers.
- Furthermore, if the training is not culturally relevant to them or does not resonate to the local farming context, training fails to successfully involve the farming community.

3. **Gender-related limitations:**

- Men are typically dominant in public spaces where agricultural knowledge is shared but women are usually confined to households or household areas limiting their access to training and knowledge (Simiyu and Foeken, 2014).
- Women are not just seen—and occasionally may view themselves—merely as helpers, which can lead male family members, as well as extension workers, to disregard their need for capacity building and training.
- All of this bias reduces women's participation in decision-making, access to resources and knowledge, limits their self-employment and independence potential, and hence can limit inclusive agricultural development.
- Lack of follow-up or practical demonstrations:
- Farmers generally find it difficult to apply what they have learned theoretically, without getting involved in hands-on-experience and consistent-follow-by the trainers. To effectively learn complex topics such as soil testing, pest management, irrigation systems, or organic composting, its practical demonstration is very important.
- Farmers are left on their own to experiment these new practices without consistent follow up, which leads to mistakes on their part and which leads to discouragement, lack of confidence and further leads to the farmers returning to the old traditional practices (Mwaniki et al., 2017).

The Way Forward

To truly empower the farming community, agricultural training must become smarter, more inclusive, and rooted in local realities. Training should use simple language, local dialects, and visual aids to ensure accessibility, especially for farmers with low literacy. Interactive methods such as storytelling, role-plays, peer learning, and field demonstrations make learning more engaging and practical. Involving local trainers familiar with the language, culture, and farming conditions enhances relevance and effectiveness. To reach remote areas, training can be delivered through radio, videos, mobile apps, and voice-based services—but this also requires prior training in digital tools. Inclusivity must be a priority, with a focus on engaging women, youth, and smallholder farmers who often face barriers in accessing agricultural education. Gender-sensitive approaches and inclusive policies are essential to promote equal participation and recognition in the sector. Finally, training should be continuous rather than one-time. Regular follow-ups, refresher sessions, and community-based support systems help farmers retain knowledge and adapt to changing conditions. By making training simple, practical, inclusive, and ongoing, the farming community can be better equipped to meet both present and future challenges.

Conclusion

As the farming industry keeps adapting to climate change, market fluctuations, and increasing food needs, the need for enabling farmers through appropriate training cannot be overemphasized. Training is no longer a luxury—it is a necessity. Farmers can make better choices; implement sustainable practices and boost productivity and income, if they are given an opportunity to access appropriate, timely, and practical know-how. The inclusive training ensures that no segment is left behind, whether it is women, youth or smallholders. Concurrently continuous learning ensures that farming communities remain resilient to change. Farmers need to be recognized not only as food producers, but also as innovators and entrepreneurs in order to build a stronger agricultural sector. A farmer can be educated and this can have a ripple effect, which can be positive for the whole farming community. Empowered farmers are the key to food security and rural development—because when farmers nourish their knowledge, they grow everything else with it.

References

Gupta, A., Ponticelli, J., & Tesei, A. (2024). Language barriers, technology adoption and productivity: Evidence from agriculture in India. Review of Economics and Statistics, 1-28.

Mwaniki, F. N., Gichuki, C., Mwangi, M., Mburia, P., & Wandago, B. (2017). Addressing challenges in communicating adaptation practices to smallholder farmers in Kenya through a radio intervention. Journal of Agriculture and Environment for International Development, 111 (2), 279 – 322. https://doi.org/10.12895/jaeid.20172.589.

National Institute of Agricultural Extension Management (2018). Inspiring Stories from Innovative Farmers.https://www.manage.gov.in/managecia/Success%20Stories%20-%20Farmers%20.pdf

Raghuvanshi, K. (2014). The Problems of Agriculture in the Indian Context. International Journal of Computer Science & Management Studies, 14(3), 2231 –5268

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. https://doi.org/10.1155/2021/8924087.

Simiyu, R., and D. Foeken (2014). Gendered divisions of labour in urban crop cultivation in a kenyan town: Implications for livelihood outcomes. Gender, Place & Culture, 21 (6), 768–784. https://doi.org/10.1080/0966369X.2013.810602 (open in a new window).

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Empowering Farmers Through Seed Priming: Enhancing Germination and Crop Yield

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Seed priming is a simple, low-cost, and farmer-friendly technique that enhances seed germination, accelerates seedling establishment, and boosts crop productivity. Especially relevant for smallholder and resource-poor farmers, seed priming helps mitigate early-season risks and improves resilience against environmental stress. This review highlights the physiological, biochemical, and practical aspects of seed priming across major crops, with a focus on its role in sustainable agriculture and farmer empowerment. The article also discusses adoption challenges and future directions for wider implementation in Indian agriculture.

Keywords: Seed priming, germination, seedling vigor, hydropriming, osmopriming, climate resilience, sustainable agriculture, farmer empowerment

Introduction

Germination is a critical stage in crop development, often influenced by seed quality and environmental conditions. Inconsistent rainfall, poor soil quality, and seed-borne issues frequently result in suboptimal germination and weak seedling emergence, especially in rainfed regions of India. To address these challenges, seed priming has emerged as an effective technique to improve germination efficiency and establish robust seedlings. It is especially beneficial for smallholder farmers who require cost-effective technologies to improve productivity under variable climatic conditions. By improving seed performance, priming contributes not only to better crop yield but also to income security and climate resilience.

Concept of Seed Priming

Seed priming refers to the controlled hydration of seeds before sowing to initiate pre-germinative metabolic activity without actual germination (radicle protrusion). Once primed, the seeds are re-dried to their original moisture content and can be sown using traditional methods. This pre-treatment reduces the lag time between sowing and emergence, leading to faster, more uniform germination and better stand establishment.

Methods of Seed Priming

Methods and Crop-Specific Procedures of Seed Priming

Seed priming methods vary based on crop type, seed size, climatic conditions, and specific objectives. Commonly used priming types and their crop-specific procedures are outlined below:

Hydropriming involves soaking seeds in clean water for 6–12 hours and drying them in shade. It is widely used in crops like rice, wheat, pulses, and maize. This method improves uniform emergence and reduces seedling mortality in rainfed conditions.

Osmopriming requires soaking seeds in a solution of polyethylene glycol (PEG) or mannitol at a controlled osmotic potential (e.g., –1.5 MPa) for 12–24 hours at room temperature. Crops like wheat, tomato, and soybean respond well to this method, especially under drought-prone environments.

Halopriming involves the use of salt solutions such as potassium nitrate (1%) or calcium chloride to enhance germination under salinity. Seeds of mustard, groundnut, and certain vegetables are haloprimed for 6–8 hours before sowing.

Hormonal priming is done by soaking seeds in dilute solutions of plant growth regulators like gibberellic acid (GA_3 at 50–100 ppm) for 4–6 hours. This method promotes early growth in rice, tomato, and okra.

Biopriming combines hydration with microbial inoculation using beneficial fungi or bacteria (e.g., *Trichoderma*, *Pseudomonas*). It is particularly effective in pulses like chickpea and pigeon pea for improving disease resistance and nutrient uptake.

Nutripriming uses micronutrient solutions such as zinc sulfate or iron sulfate to correct early-stage nutrient deficiencies. Maize, rice, and vegetable crops benefit from 6–8 hour nutripriming treatments followed by shade drying.

In all cases, seeds must be re-dried to safe moisture levels (~10–12%) to ensure handling ease and storage safety.

Physiological and Biochemical Basis

During priming, key physiological changes occur within the seed. Enzymes such as α-amylase are activated, which help mobilize stored carbohydrates for embryo growth. The repair of DNA, proteins, and cellular membranes begins, preparing the seed for rapid cell division and expansion upon sowing. Additionally, antioxidant systems are strengthened, which reduces oxidative stress under adverse conditions such as drought or high temperature. These changes collectively enhance seed vigor and resilience during the critical germination phase.

Benefits in Major Crops

Seed priming has demonstrated significant benefits in a wide range of crops. In rice, particularly under rainfed and direct-seeded systems, priming improves germination speed, reduces seedling mortality, and enhances tillering. Wheat responds well to osmopriming, with improved early growth and drought tolerance. Pulses like chickpea and mungbean show enhanced nodulation and nutrient uptake when bioprimed. In vegetables such as tomato and okra, hormonal and nutripriming lead to early flowering, better fruit set, and higher marketable yield. Oilseeds like soybean and groundnut also show improved emergence and plant stand under variable soil moisture conditions.

Role in Climate-Resilient Agriculture

With climate change intensifying abiotic stress conditions such as erratic rainfall, drought, and heat waves, seed priming offers a practical and accessible climate adaptation strategy. It allows seeds to germinate even under limited moisture availability, enhances tolerance to salinity, and supports early root development for better water and nutrient uptake. By improving crop establishment and early vigor, primed seeds contribute to higher yield stability and better input efficiency under unpredictable environmental conditions.

Empowering Farmers through Seed Priming

Seed priming is a farmer-friendly technology that empowers rural communities in several ways. It requires minimal input and can be performed using locally available resources, making it ideal for small and marginal farmers. The technique can be easily taught and adopted at the household or community level, enabling farmers to reduce the risk of crop failure, improve productivity, and increase farm income. Moreover, it enhances self-reliance by reducing dependence on expensive agrochemicals or commercial seed treatments.

Women farmers and self-help groups have successfully implemented seed priming for vegetable nurseries and pulse cultivation, leading to increased participation and recognition in agricultural decision-making. Extension programs by KVKs and agricultural universities have shown strong adoption rates and measurable improvements in crop yield and resilience.

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Constraints and Future Scope

Despite its advantages, several constraints limit the widespread adoption of seed priming. These viability during storage, and limited extension support in remote regions. To overcome these challenges, there is a need for increased investment in awareness campaigns, demonstration plots, and training programs.

Future innovations could include nanopriming (using nanoparticles to deliver nutrients), seed coating technologies, and the integration of priming with digital advisory platforms for precision agriculture. Research institutions should focus on developing crop-specific priming protocols and validating them under different agro-climatic zones to support policy formulation and field-level implementation.

Conclusion

Seed priming is an effective, low-cost, and sustainable solution for enhancing seed performance, improving crop yields, and building resilience against climate stress. Its simplicity and adaptability make it highly suitable for resource-poor farmers in developing countries. With appropriate training, extension support, and policy backing, seed priming can serve as a powerful tool to strengthen

include lack of awareness, absence of standardized protocols for different crops and varieties, difficulty in maintaining primed seed agricultural productivity, ensure food security, and empower farmers across India and beyond.

References

1. Farooq, M., Basra, S.M.A., Wahid, A., & Nawaz, A. (2006). Seed priming enhances emergence and yield of direct-seeded rice. *Crop Science*, 46(4), 2092–2099.
2. Harris, D., Raghuwanshi, B.S., Gangwar, J.S., Singh, S.C., Joshi, K.D., & Rashid, A. (2001). On-farm seed priming: using participatory methods to revive and refine a key technology. *Agricultural Systems*, 69(1-2), 151–164.
3. Basra, S.M.A., et al. (2005). Improving germination and early seedling growth in wheat by hormone and osmotic priming. *Acta Agronomica Hungarica*, 53(4), 433–439.
4. ICAR–CRIDA. (2022). *Technical Manual on Seed Priming for Rainfed Agriculture*. Hyderabad, India.
5. Singh, G., Meena, R.S., & Ghosh, P.K. (2023). Biopriming as a tool for enhancing crop productivity and resilience. *Indian Journal of Agronomy*, 68(1), 56–62.

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THE AFTERLIFE OF HARVEST-VALUE CREATION FROM WASTE TO WORTH

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Introduction

In horticulture, waste valorization transforms by-products like peels, seeds, stems, and spoiled produce into valuable goods, reducing losses and promoting sustainability. Due to high perishability, post-harvest losses can reach 5-60%, generating large waste volumes across the value chain. Improper disposal harms the environment through landfill overflow and greenhouse gas emissions. Rich in nutrients and bioactive compounds, horticultural waste can be re-purposed into bioenergy, animal feed, fertilizers, medicines, and functional food ingredients. This process supports a circular economy, enhances food security, reduces environmental impact, and creates economic opportunities, positioning horticulture as a leader in sustainable resource use.

Importance of Water Valorization in Horticulture

- Horticultural crops require high water input; technologies like drip irrigation and fertigation ensure precise water delivery, reducing waste and boosting yields.
- Recycling wastewater in horticulture activities can help cut freshwater use dramatically. For example, allow up to 90% of greenhouse water to be reused, so harmonize with circular economy concepts and lowering environmental effects.
- The use of technologies such as hydroponics, aeroponics, and closed-loop systems permits soil-free cultivation and efficient water management, therefore promoting plant development in addition to water conservation.

Implementing water valorization strategies helps to promote sustainable agriculture by conserving water resources, minimizing environmental impact, and improving food security.

Impact of Value Addition on Horticultural Waste

- **Reduces Environmental Pollution:** Converting horticultural waste into compost, biogas, or biofertilizers reduces landfill use and methane emissions, with composting cutting environmental impact by 40–70% compared to landfilling or incineration.
- **Enhances Resource Efficiency:** Waste valorization recovers bioactive compounds like polyphenols and fibers from fruit peels, creating products such as food additives, bioplastics, and biofuels, supporting resource efficiency and a circular economy.
- **Improves Soil Fertility**: Processing organic waste into compost or biofertilizers enriches soil, boosts crop growth, and reduces synthetic fertilizer use. Biochar improves soil structure and nutrient retention.
- **Supports Food Security:** Valorization reduces post-harvest losses (5-30% in horticulture) by utilizing surplus or blemished produce for processed goods, ensuring year-round availability of nutritious products.
- **Promotes Sustainable Industry**: Horticultural waste valorization into biogas, enzymes, or bioplastics reduces fossil material use, cuts carbon emissions,

- and supports Sustainable Development Goals.

Horticultural Waste as Substrate

Using horticulture waste as a base for value-added goods is a sustainable technique that diminishes environmental effects while simultaneously creating economic potential. Several novel approaches have been developed to turn horticulture byproducts into useful resources.

- **Composting Substrate**: Horticultural waste (e.g., vegetable trimmings, fruit peels) serves as a nutrient-rich substrate for composting. It produces organic fertilizers with high carbon and nitrogen content, improving soil fertility by 20-40% compared to synthetic inputs.
- **Bioenergy Production**: Lignocellulosic waste (e.g., straw, stalks) acts as a substrate for anaerobic digestion or fermentation, yielding biogas or bioethanol.
  For example, sugarcane bagasse can produce 180-280 L of biogas per kg of dry matter.
- **Growing Media Alternative**: Processed waste like coconut coir, rice husks, or composted green waste can replace peat in horticultural substrates, offering sustainable growing media with comparable water retention and aeration for plant growth.
- **Bioactive Compound Extraction**: Waste such as citrus peels or grape pomace serves as a substrate for extracting valuable compounds (e.g., pectin, antioxidants), used in food, pharmaceutical, or cosmetic industries, reducing waste by up to 50%.
- **Mushroom Cultivation**: Horticultural residues like wheat straw or corn cobs provide ideal substrates for growing edible mushrooms (e.g., oyster, shiitake), with yields of 0.5-1 kg of mushrooms per kg of dry substrate.
- **Environmental Benefits**: Using waste as a substrate reduces landfill disposal, cutting methane emissions by 30-60% and supporting circular economy principles by recycling nutrients back into agricultural systems.

Conclusion

Horticultural waste valorization transforms by-products like peels and trimmings into valuable resources, reducing landfill use and greenhouse gas emissions through biofuel and biogas production. It boosts the economy by creating value-added products such as animal feed, sustainable chemicals, and microbial media. Technologies like dehydration and thermophilic biogas systems show promise, though challenges like waste variability remain. Success depends on innovative, context-specific methods that balance environmental, economic, and social impacts, positioning waste valorization as key to sustainable agriculture.

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Sustainable Saffron Production: Exploring the Potential of Indoor Cultivation Systems

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Saffron is renowned as the world's most expensive spice, is traditionally cultivated under specific agro-climatic conditions that limit its productivity and availability. This article explores innovative approaches to saffron cultivation through indoor cultivation systems, highlighting their potential to overcome the constraints of conventional methods. Indoor cultivation enables precise control over temperature, humidity, light, and other vital growth factors, leading to enhanced quality, increased yield, and year-round production. The study outlines the procedures, requirements, and benefits of both techniques, emphasizing the role of controlled conditions in ensuring uniformity, sustainability, and profitability. With proper planning and technological integration, indoor saffron cultivation can revolutionize spice production, offering a scalable model for modern agribusiness ventures.

Keywords: Conventional, efficient, sustainability and agribusiness ventures

Introduction

Saffron, scientifically known as *Crocus sativus L.*, is a perennial herbaceous plant belonging to Iridaceae family. It is propagated through mother corms. The spice known as Saffron derived from the red stigmas of Saffron flower. It is popularly known as **'Red gold'**. The quality of the spice is dependent on its colour (*Crocin*), taste (*Picrocrocin*) and Odour (*Safranal*). The spice is acclaimed for its use in food as a flavouring as well as a colouring agent. It is also a component of many medicines. Saffron is considered as a symbol of prosperity and purity in many traditions. It is used in religious ceremonies and offerings, particularly in Buddhism and Hinduism. Saffron has its variety of uses in food, cosmetic, pharmaceutical, perfumery and textile dyes industries but the high labour requirement, low yield, limited cultivation area make it so expensive. Saffron is cultivated across a wide area, from the Mediterranean Spain to India. India contributes 5% of the world's total production of which 90% is supplied only from Jammu & Kashmir region. In Jammu and Kashmir region, the total area under saffron cultivation is 3715 hectares, with a productivity ranging from 3.0 to 4.0 kg per hectare.

Figure 1. Saffron field

Figure 2. Saffron flower with red stigmas

Cultivation of saffron under normal conditions:

Saffron cultivation involves planting saffron corms in well- drained, fertile soil during late summer or early fall. The plant thrives in sunny, cool climates with adequate rainfall. Saffron is a labour- intensive crop, with the three stigmas from each flower being hand- picked, dried, and then used as a spice and colorant. But Saffron cultivation faces numerous constraints in normal growing conditions. These include specific temperature and humidity requirements, well drained and fertile soil, susceptibility to pest & diseases, requiring well trained and skilled labours. Therefore, the cultivation of saffron in indoor environment paves way for meeting optimum climatic conditions, monitoring the growth and increasing yield.

Figure 3. Saffron cultivation in open field

Cultivation of saffron under controlled conditions

In the recent days, saffron are cultivated under a controlled condition in all the regions because of the huge demand. The are some of the benefits when the saffron is cultivated under the controlled condition.

- Saffron plants require specific conditions to thrive, including well drained soil, ample sunlight and proper irrigation. Controlled environments allow growers to monitor and adjust these conditions to ensure optimal growth and yield.
- Cultivating saffron in a controlled environment allows for better quality control over the entire cultivation process. This includes monitoring factors such as temperature, humidity and light exposure to ensure saffron produce meets certain quality standards.
- Cultivating saffron under controlled conditions can help protect the plants from pests and diseases that can impact their growth and yield. By controlling the environment, growers can minimize the risk of infestations and infections that could damage the crop.
- Controlled environments can help optimize saffron production by providing plants with ideal conditions for growth this can result in higher yields per square meter compared to traditional outdoor cultivation methods.
- By controlling factors such as temperature, humidity and light exposure, growers can ensure that the saffron produced is consistent in quality and flavour. This is important for meeting the expectations of consumers and maintain a good reputation in the market.

Figure 4. Saffron cultivation in controlled conditions

Basic requirements for indoor cultivation of saffron:

Indoor saffron cultivation in enclosed spaces allows for maximized density. Using a 60-meter-long hall, it is possible to grow 4 metric tons of saffron bulbs, with a conversion rate of 10 kg of flowers to 1 kg of dried saffron, each tonne of saffron bulbs can produce approximately 2 kg of dried saffron. This means that indoor cultivation in just 100 square meters can yield the same amount as outdoor cultivation on a one-hectare land area. However, successful indoor cultivation requires proper planning, infrastructure and management. Factors like lighting, temperature control and nutrient supply must be carefully regulated for optimal growth and yield. The materials such as corms are carefully placed in racks within the dark room to create an environment with stable temperatures which contributes to improved outcomes. The entire cultivation process, from planting to emergence of flowers, typically takes around three months. Following the harvest, the saffron buds are preserved in open fields or kitchen garden to be used for future seasons, ensuring a continuous and sustainable production cycle. Healthy and disease-free corms of medium size bulb is used for indoor cultivation of saffron.

Procedure for cultivation of saffron under controlled conditions:

1. The corms are treated with fungicide to prevent rotting and ensure their health and viability.
2. The corms are sorted based on their size to ensure uniformity and optimal growth.
3. The corms are placed in plastic trays, providing a sustainable environment for their growth and development.
4. The trays with corms are then transferred onto racks, allowing for better organization and management of cultivation process.
5. The racks with the trays of corms are placed in a dark environment for a period of 120 days. This extended dark phase is necessary for the corms to undergo the required physiological changes and prepare for sprouting and flowering.

Conclusion:

Indoor cultivation of saffron presents a sustainable and innovative alternative to the existing traditional methods. By using controlled environments, growers can overcome climatic limitations, reduce pest infestations, and produce high- quality saffron throughout the year. By overcoming challenges and adopting best practices, this innovative method can contribute to the global supply of this valuable spice. Although the process requires an initial investment and careful monitoring, the long-term benefits such as increased yield, better quality & year-round availability make it a promising venture in modern agriculture. With growing demand and advances in indoor farming technologies, indoor saffron cultivation holds great potential for both commercial and personal use.

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BLOOM TO BITE: THE RISE OF EDIBLE FLOWERS AND POSTHARVEST INNOVATIONS

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Flowers possess an eminent place in various fields including arts, religion, culinary and health since olden days. The popularity of edible flowers particularly increased since late 1980s. The increased number of magazines, articles, recipe books and websites on this theme as well as the growth in research on this theme increases the market for edible market. However, the edible flower market gains lesser attention than the other horticultural crops because the production of the edible flowers is very low and it is highly perishable in nature. Edible flowers' shelf-life ranges from 2- 5 days after harvest. Compared to other flowers in the market, the edible flowers are considered as more vulnerable. Presently edible flowers are mostly sold in fresh form or packaged in small, rigid plastic packages which is then kept in refrigeration conditions.

Edible Flowers

Edible flowers include Borage, hibiscus, elderberry blossoms, centaurea, rose, pansy, nasturtiums and flowers of alliums, mint, thyme, summer savory, marjoram and the common sage. Edible flowers which are commonly eaten are not recognized as flowers i.e. artichoke, broccoli and cauliflower as they are considered as vegetables.

Postharvest Technologies Applied

Preserving the quality of edible flowers is considered important as they concern in health of the consumers. The growing non-thermal techniques and packaging techniques used for edible flower preservation includes cold storage, drying, high hydrostatic pressure, irradiation and innovations in packaging.

Cold Storage

Cold storage extends the shelf life of edible flowers by delaying the senescence and quality deterioration. Cold storage reduces the respiration rate of the produce and thus the ethylene production is low which enhances quality of edible flowers. The quality of edible flowers not including *Brassica species* and artichoke are good at the temperature range between -2.5 and 5^{o} C up to two weeks. Temperature range from 0 to 10^{o} C is good for artichoke, cauliflower and *Brassica species*. Different effects have been noted with the different temperature on the quality and the appearance of edible flowers.

Drying

Hot-air drying, sun drying, microwave drying, freeze drying, osmotic drying, cool wind drying are some of the drying methods used for the preservation of edible flowers. Among these the hot air drying and sun drying are considered as classical methods of drying. Among the various drying methods, freeze drying is characterized with the retention of bioactive compounds in purple coneflower, decreased losses of carotenoids in daylilies, increased levels of lutein in marigold and higher antioxidant activity in black locust flowers.

High Hydrostatic Pressure

High hydrostatic pressure is the potential method used alternative to heat treatments, for assuring safety and quality attributes of food products. Edible flowers show different effects under HHP. Pansies at 75/5 or 75/10 MPa per minute resulted in good appearance and extended storage life of 20 days at 4º C temperature. HHP is considered the promising technology for edible flower preservation.

Irradiation

Irradiation is the physical process which is used to eliminate or inhibit undesirable microorganisms from food products. Different mechanisms of irradiation are carried out namely, Ionizing and Nonionizing radiation. A study states that the secondary metabolism in *Viola tricolor* was enhanced by the application of irradiation. Ionizing radiation is applied in limited doses to edible flowers so that it doesn't cause any changes in the appearance and quality attributes.

Packaging

The high perishability of edible flowers is proportional to the respiration rate. The factors influencing respiration are temperature, harvesting time and the packaging material used. Presently the edible flowers like centaurea, pansies and borage are being packed in clamshell containers. Microperforated and Nonperforated packaging in broccoli shows prolonged storage life of 28 days accompanied with retention of quality attributes. Different effects have been noted with the different packaging methods used in the edible flowers. Packaging ensures physical protection of edible flowers. Nasturtium packaged in CO_2 (3-5%) and O_2 (10-13%) shows good results due to quality improvement of flowers. Use of 1-MCP maintains fresh appearance and enhances shelf life of edible flowers.

Conclusion

Edible flowers' growing appeal is reflection of larger movement in modern diets to include more practical, aesthetically pleasing, and natural foods. Edible flowers are a special contribution to the food and health industries since they provide not only aesthetic value but also nutritional and medicinal advantages. To preserve their quality and safety, however, rigorous postharvest handling is required due to their delicate structure and extreme perishability. Modified environment packaging, cold chain logistics, edible coatings, and natural preservatives are examples of postharvest technological advancements that have greatly increased the edible flowers' shelf life, sensory qualities, and microbiological safety. In order to increase their commercial viability and satisfy customer demands for sustainability and freshness, these advancements are essential.

Prospects for the Future

Even with recent improvements, there are still a number of issues that need more research. Postharvest management, traceability, and supply chain transparency may be improved by integrating digital tools like blockchain, artificial intelligence, and remote sensing. Edible flowers have the potential to play a significant role in sustainable agri-food systems in the near future, with interdisciplinary efforts and increased awareness among consumers and producers.

Artificial Intelligence in Insect Research: A Technological Leap in Entomology

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The field of entomology is undergoing a rapid transformation with the integration of Artificial Intelligence (AI). Traditionally, insect research has relied heavily on manual techniques that are labour-intensive and often limited in scale. AI technologies, including machine learning, image recognition, and behavioural modelling, now offer a powerful toolkit to accelerate and refine the study of insects. This article explores the diverse applications of AI in insect science, including species identification, behavioural analysis, population monitoring, and pest control, and highlights its role in enhancing accuracy, efficiency, and ecological understanding in entomological studies.

Keywords: artificial intelligence, insect research, species identification, machine learning, entomology, behavioural analysis

Introduction

Insects constitute the largest and most diverse group of organisms on Earth, performing essential roles in pollination, decomposition, and as components of food webs. Despite their ecological significance, the complexity and scale of studying insects have long posed challenges for researchers. With the emergence of AI technologies, entomologists now have the tools to analyse vast amounts of data and gain deeper insights into insect biology and behaviour. This article delves into the pivotal role AI is beginning to play in modern insect research, ushering in a new era of technological advancement in entomology.

Automated Species Identification

One of the foremost applications of AI in entomology is the automated identification of insect species. Using computer vision and deep learning, AI models can be trained on large datasets of insect images to recognize and classify species with remarkable accuracy. Tools such as convolutional neural networks (CNNs) have been employed to distinguish between closely related species based on morphological features such as wing patterns, antennae, and coloration (Valan et al., 2019). Mobile apps and digital platforms like iNaturalist now enable real-time species identification, aiding researchers and citizen scientists alike.

Behavioural Tracking and Motion Analysis

AI-powered systems are increasingly used to monitor insect behaviour under both laboratory and natural conditions. By applying machine learning algorithms to video footage, researchers can track movement patterns, interactions, and responses to environmental stimuli. For instance, AI has been used to decode the waggle dance of honeybees and to analyse mating rituals, predator-prey interactions, and foraging behaviour (Wario et al., 2017). These insights are valuable for understanding ecological roles and adapting conservation strategies.

Ecological Monitoring and Pest Forecasting

The deployment of AI in ecological monitoring allows for efficient analysis of population dynamics and distribution patterns. Smart traps and sensor networks equipped with AI software can automatically detect, count, and log insect activity, enabling real-time monitoring of pest

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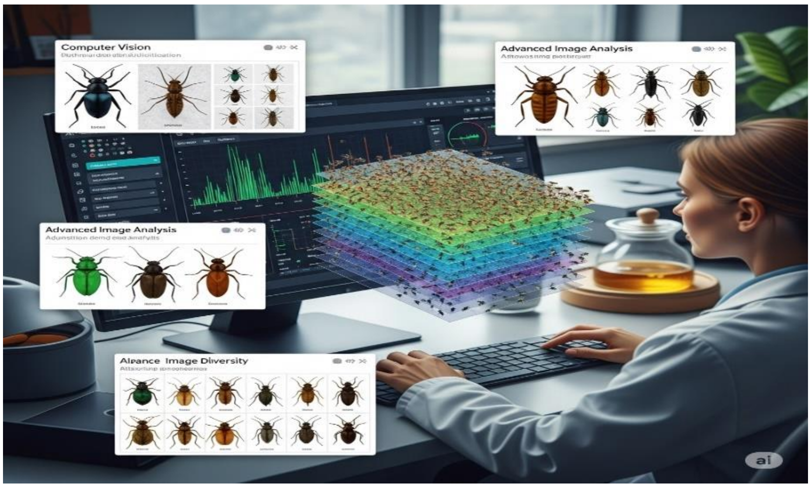
species in agricultural fields. Predictive models powered by machine learning can forecast pest outbreaks based on environmental conditions, previous data, and insect movement trends (Sarfraz et al., 2021). This leads to more precise and sustainable pest management strategies.



Data Mining and Bioinformatics

AI facilitates the integration and interpretation of complex datasets, including genomic, ecological, and behavioural data. Through natural language processing and data mining, AI systems can extract patterns from scientific literature, aiding in hypothesis generation and knowledge synthesis. In bioinformatics, AI tools are used to analyse insect genomes, identify gene functions, and explore evolutionary relationships, providing new avenues for understanding insect physiology and adaptation (Ding et al., 2021).

Challenges and Limitations

Despite its promise, the use of AI in entomology faces several challenges. These include the need for high-quality training datasets, the risk of algorithmic bias, and the complexity of interpreting AI-generated outputs. Furthermore, integrating AI into field research requires interdisciplinary collaboration and significant technical resources. Ethical considerations also arise in the use of automated surveillance tools in natural habitats.

Future Prospects

As AI technologies continue to evolve, their integration into entomological research is expected to expand. Advances in edge computing, miniaturized sensors, and drone-based monitoring may further enhance data collection and analysis in remote or sensitive ecosystems. Collaboration between entomologists, data scientists, and engineers will be crucial in harnessing AI's full potential for biodiversity conservation, agricultural resilience, and ecosystem monitoring.

Conclusion

Artificial Intelligence represents a transformative force in the field of insect research. By automating identification, enhancing behavioral analysis, and enabling predictive ecological models, AI is redefining the boundaries of entomological studies. Embracing these technologies not only improves research efficiency but also opens new frontiers in understanding the complex and dynamic world of insects.

References

Ding, Y., Chan, W.Y. and Li, H., 2021. Artificial Intelligence in Insect Genomics: Unlocking Evolutionary Insights. *Insect Molecular Biology*, 30(2): 121–130.

Sarfraz, R.M., Wang, X. and Chen, D., 2021. Smart Pest Monitoring Using AI-Driven Image Recognition and Forecasting. *Journal of Integrated Pest Management*, 12(1): 45.

Valan, M., Makonyi, K., Maki, A., Vondráček, D. and Ronquist, F., 2019. Automated Taxonomic Identification of Insects with Expert-Level Accuracy Using Deep Learning. *Systematic Biology*, 68(6): 876–895.

Wario, F., Wild, B., Rojas, R. and Landgraf, T., 2017. Automatic Detection and Decoding of Honeybee Waggle Dances. *PLoS ONE*, 12(12): e0188626.

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Fostering Resilient Rural Economies through Climate-Smart Agriculture

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Introduction

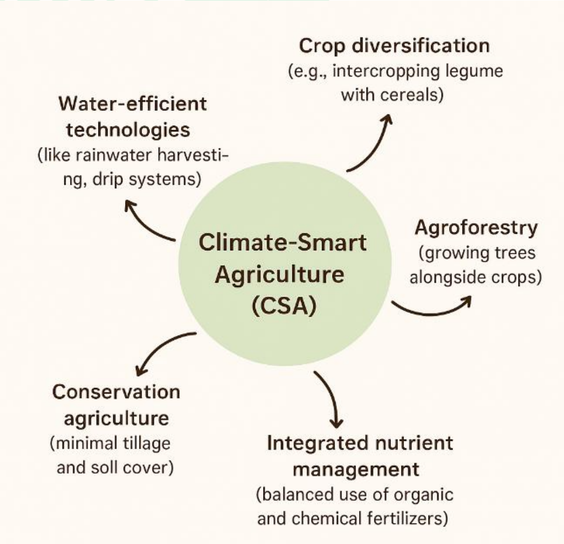
Rural economies around the world, especially in agrarian nations like India, are intricately tied to the rhythms of agriculture. For millions of smallholder farmers, the land is not just a means of livelihood, it is their identity and sustenance. However, in recent years, the certainty of seasons and the reliability of harvests have been disrupted by the growing impacts of climate change. Erratic rainfall, prolonged droughts, unseasonal floods, and rising temperatures are making traditional farming increasingly uncertain and economically fragile.

In this challenging scenario, Climate-Smart Agriculture (CSA) has emerged as a promising approach to ensure that agriculture remains both viable and resilient. It promotes techniques and practices that not only enhance productivity but also help farmers adapt to climatic stresses while contributing to environmental sustainability. CSA encourages a holistic transformation of farming, integrating new technologies, indigenous knowledge and sustainable resource management.

This article explores how CSA can serve as a critical strategy for reviving rural economies, reducing climate vulnerability, and empowering farmers especially women and youth. By shifting from reactive coping to proactive resilience, CSA offers a pathway toward more secure, adaptive, and thriving rural communities. In an era of growing environmental uncertainty, it is time to rethink how we cultivate, conserve and coexist.

Understanding Climate-Smart Agriculture (CSA)

Climate-Smart Agriculture (CSA) is not a single technique or solution, but rather a broad, integrated approach to farming that helps smallholder farmers adapt to changing climatic conditions while ensuring food security and environmental sustainability. It was developed in response to the growing realization that traditional agricultural practices are no longer sufficient in the face of climate variability, unpredictable rainfall, rising temperatures and frequent extreme weather events.



At its core, CSA seeks to achieve three primary objectives: increasing agricultural productivity and incomes sustainably, building resilience and adaptation to climate change, and reducing greenhouse gas emissions from agricultural practices wherever possible. Unlike conventional farming approaches, CSA is context-specific, it does not prescribe a fixed set of practices but instead encourages farmers to choose and adapt methods that suit their local climate, geography, and socio-economic conditions.

How CSA Nurtures Rural Economies?

Agriculture is the backbone of rural livelihoods. But for too long, this backbone has been strained by climate extremes, fluctuating markets and poor infrastructure. CSA brings a holistic approach to revitalizing this sector.

1. Securing Farmers' Incomes

Traditional farming is increasingly vulnerable to yield losses due to erratic weather. CSA helps mitigate this risk. For instance, switching to early-maturing or stress-tolerant crop varieties can help maintain yields even under adverse conditions. Efficient water use and reduced input dependency also bring down costs.

Additionally, CSA promotes year-round farming through crop rotation and intercropping, which increases food and income security. When farmers grow a combination of cereals, pulses and vegetables, they reduce their reliance on a single crop and market.

2. Reducing Vulnerability

The poorest households are often the most affected by climate shocks. CSA enables them to manage risks proactively, rather than reactively. For example, community-based weather advisories or climate forecasts allow farmers to plan sowing dates better. Livelihood diversification like integrating livestock, fish farming or value-added processing also insulates rural economies from total collapse during bad seasons.

3. Reviving Common Resources

Rural economies don't thrive in isolation; they're deeply connected to the landscape. CSA practices like watershed development, agroforestry and organic farming improve soil health, rejuvenate groundwater and protect biodiversity. A healthier environment ultimately supports more robust rural livelihoods, especially for women and landless laborers dependent on common resources like forests, ponds and grazing lands.

Enablers: Technology and Innovation in CSA

Modern agriculture is entering an exciting phase where technology meets tradition. In the context of CSA, digital innovations are unlocking new opportunities for smallholder farmers.

1. Mobile-based Advisory Services

Apps like Kisan Suvidha and platforms like Digital Green provide timely information on weather forecasts, pest outbreaks, best practices, and market prices. Such services help farmers make data-informed decisions, minimizing risk and loss.

2. GIS and Remote Sensing

Geographic Information Systems (GIS) and satellite imagery help monitor soil health, predict crop yields and assess flood-prone areas. These tools are especially useful for agricultural planners and NGOs designing community-level CSA programs.

3. Smart Irrigation Systems

Solar-powered pumps and automated drip irrigation systems are making water use more precise and sustainable. In water-scarce areas, this technology has dramatically improved the efficiency of irrigation while reducing energy costs.

4. Climate-Resilient Seeds

Scientific institutions like ICAR and ICRISAT have developed climate-resilient seed varieties that are drought, flood and salinity-tolerant. These varieties are game changers for marginal farmers who cannot afford to lose even one season's income.

Empowering Rural Women and Youth through CSA

No discussion on rural development is complete without recognizing the silent yet substantial role of women and youth. CSA is not just a technical transformation; it's a social one, too.

1. Women as Climate Leaders

In many parts of rural India, women perform 60–80% of agricultural tasks. Yet, they often lack access to land, credit, and decision-making power. CSA offers a chance to change that

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narrative. Programs that train women in composting, seed saving, kitchen gardening or organic farming not only boost household nutrition but also empower them economically.

Women-led Self-Help Groups (SHGs) are increasingly adopting CSA-based microenterprises like bio-fertilizer units, food processing and nursery management thus generating income and leadership opportunities.

2. Rural Youth and Agri-Tech

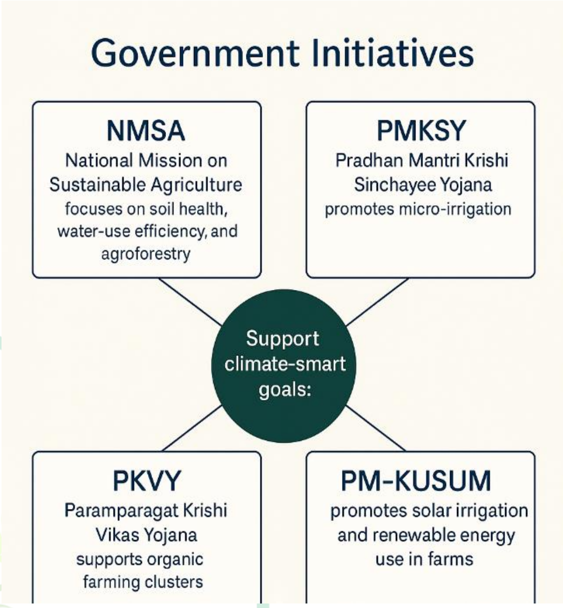
Youth often migrate to cities due to the lack of rewarding opportunities in villages. But CSA, when combined with agri-tech startups and digital farming models, is making agriculture attractive again.

Digital platforms like AgriApp, DeHaat and Krishi Network are opening avenues for young agripreneurs. With proper training and access to incubation centers, rural youth are exploring careers in drone-based crop monitoring, agri-consulting and sustainable input supply chains.

Policy and Institutional Support: The Backbone of CSA

While farmers play a pivotal role in adopting climate-smart agricultural practices, the successful scaling and sustainability of these efforts depend heavily on robust policy frameworks and institutional mechanisms. Government policies and institutional support act as the backbone of Climate-Smart Agriculture (CSA), ensuring that innovations reach the grassroots and become integrated into everyday farming systems.

Several national-level schemes in India have incorporated CSA principles either directly or indirectly. For example, the National Mission on Sustainable Agriculture (NMSA), a key component of the National Action Plan on Climate Change, promotes sustainable farming through soil health management, water-use efficiency, and agroforestry. Similarly, the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) encourages micro-irrigation techniques like drip and sprinkler systems, which are vital for water-stressed regions. Other initiatives such as the Paramparagat Krishi Vikas Yojana (PKVY) promote organic farming clusters, contributing to soil health and reduced chemical input use.



In addition to government policies, Farmer Producer Organizations (FPOs) have emerged as strong vehicles for collective action. They help small and marginal farmers gain better access to CSA technologies, credit, and markets. By pooling resources, FPOs make it feasible for farmers to adopt high-cost inputs like solar irrigation pumps, weather stations, or processing units. They also create platforms for knowledge exchange and collective marketing, which are crucial for rural resilience.

Research and extension institutions such as the Indian Council of Agricultural Research (ICAR), State Agricultural Universities (SAUs), and Krishi Vigyan Kendras (KVKs) play a central role in testing, validating and disseminating climate-smart practices. These institutions often serve as the first point of contact for rural communities to receive training, guidance and technical support. Field demonstrations, farmer field schools, and participatory trials conducted by these institutions help build trust and accelerate adoption of CSA practices.

Moreover, non-governmental organizations (NGOs) and civil society actors bring community-based experience and grassroots mobilization capabilities. They play a critical role in sensitizing farmers, tailoring CSA solutions to local needs, and ensuring that the most vulnerable such as women, tribal farmers, and tenant cultivators are included in development efforts.

In essence, policy and institutional support serve as the enabling environment that allows CSA to flourish. Without sustained investments in extension, credit, infrastructure, and training, even the most innovative practices risk remaining at the pilot stage. Therefore, aligning policy priorities with climate-resilient agriculture is not just desirable, it is indispensable for fostering resilient rural economies.

Conclusion

As climate change continues to reshape the agricultural landscape, the resilience of rural economies depends on how swiftly and thoughtfully we respond. Climate-Smart Agriculture (CSA) offers not just a set of solutions, but a new way of thinking where productivity is aligned with sustainability and where farmers become active agents of adaptation, not passive victims of crisis.

By adopting climate-resilient practices, harnessing the power of technology and enabling women and youth to lead local transformation, CSA strengthens both the ecological and economic foundations of rural life. However, for this vision to translate into widespread change, it must be backed by strong institutional support, inclusive policies and grassroots-level engagement.

The future of India's villages and indeed, rural communities around the world rests in our ability to reimagine agriculture as a climate-resilient, inclusive and dignified livelihood. CSA is not a luxury or a niche idea; it is an urgent necessity and a practical pathway toward sustainable development. In the end, resilient rural economies will not be built by chance, but by choices, choices that honor the farmer, protect the planet, and secure the food and futures of generations to come.

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Feeding the Future: The Role of Smart Farming in Global Growth

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Introduction

As the global population surpasses 8 billion, humanity faces one of its greatest challenges: how to feed everyone in a sustainable, equitable, and resilient way. Agriculture, the backbone of human civilization, must now evolve to meet the rising food demand without exhausting the planet's resources. While traditional farming methods have sustained communities for generations, they are now under growing pressure from multiple, converging threats.

Climate change has made weather patterns increasingly unpredictable, triggering droughts, floods, and pest outbreaks that threaten crops. Meanwhile, arable land is shrinking due to urban expansion, soil degradation, and deforestation. Water scarcity is affecting irrigation systems in many parts of the world, and labour shortages driven by rural-urban migration and an aging farming population are making it harder to manage farms efficiently.

These mounting pressures demand more than incremental changes, they require a paradigm shift in how we approach food production. That shift is embodied in the rise of smart farming, also known as digital agriculture or precision agriculture. This approach leverages cutting-edge technologies such as satellite imagery, drones, GPS-guided machinery, artificial intelligence (AI), Internet of Things (IoT) devices, big data analytics, and mobile platforms to revolutionize every aspect of farming from sowing to harvesting, and from field to market.

Smart farming is not just about increasing yields; it's about doing more with less. By using data to make precise decisions when to water, fertilize or spray farmers can conserve resources, reduce input costs and minimize environmental harm. In regions where farming is vulnerable or inefficient, such tools offer the potential to close yield gaps and improve profitability, especially for smallholders.

But smart farming's impact extends far beyond the farm gate. It plays a vital role in achieving global development goals, including reducing poverty, enhancing food security, creating rural employment, and boosting climate resilience. For instance, farmers using mobile apps in Africa are gaining better market prices, and precision irrigation systems in India are helping conserve water while increasing productivity. In this article, we dive deep into the world of smart farming, exploring its key technologies, global success stories, benefits, challenges, and potential for scaling up as a strategic path toward sustainable global growth and resilient food systems.

What is Smart Farming?

Smart farming refers to the application of modern information and communication technologies (ICT) in agriculture. It combines precision agriculture, data analytics, machine learning, and automation to make farming more efficient, sustainable, and responsive to environmental challenges.

Key Features of Smart Farming:

- ✓ **Internet of Things (IoT):** Smart sensors in soil, weather stations, and crops monitor environmental conditions in real time.
- ✓ **Global Positioning Systems (GPS):** Used in tractors and drones for precision field mapping and planting.

- ✓ **Artificial Intelligence (AI):** Predicts pest outbreaks, recommends fertilizer application, and assists in crop planning.
- ✓ **Automation:** Robotic harvesters and autonomous tractors reduce labor needs and human error.
- ✓ **Big Data & Analytics:** Aggregates farm data for better decision-making and yield optimization.

The traditional methods, smart farming allows farmers to apply the right amount of inputs (fertilizer, water, pesticides) at the right time and place, reducing waste and increasing productivity. Whether it's a smallholder farmer using a mobile phone app in India or a large commercial grower using drones in the U.S., smart farming adapts across scale and geography.

Smart Farming and Global Development

Smart farming is more than a technological trend, it is a vital **driver of sustainable development** worldwide.

Alignment with UN Sustainable Development Goals (SDGs):

1. **SDG 2 – Zero Hunger:** Smart technologies increase crop yields and reduce post-harvest losses, helping ensure food availability.
2. **SDG 1 – No Poverty:** By improving productivity and market access, smart farming enhances farmer incomes.
3. **SDG 13 – Climate Action:** Precision agriculture reduces the use of chemical inputs and water, lowering agriculture's carbon footprint.

In developing countries, smart farming technologies help overcome traditional constraints such as erratic rainfall, poor infrastructure, and limited market information. For example, in **Kenya**, digital platforms like *Digital Green* connect farmers with extension agents, helping them improve techniques and boost productivity. In **India,** startups like *AgNext* and *DeHaat* use AI and mobile apps to support farmers with real-time insights, soil health monitoring, and access to quality inputs. In **developed countries**, smart farming supports large-scale commercial operations. In the Netherlands, vertical farming and hydroponics allow for high-density food production with minimal land and water. Smart farming provides tools for nations to grow more food sustainably, empower rural communities, and build climate-resilient agriculture systems, key pillars for inclusive global growth.

Key Technologies in Action

As smart farming evolves, it brings together various digital tools that help farmers make more informed decisions, increase productivity, and reduce waste. Below are some of the core technologies that are transforming agriculture globally:

1. **Drones and Remote Sensing**

Drones have become a game-changer in modern agriculture by providing farmers with a bird's-eye view of their fields. Equipped with high-resolution and multispectral cameras, these flying devices capture detailed images that reveal plant health, pest infestations, water stress, and crop maturity. Remote sensing allows for early detection of issues like nutrient deficiencies or disease outbreaks, enabling farmers to respond swiftly and prevent losses. By generating accurate, real-time field data, drones support precision agriculture, reduce labor, and cut input costs.

Example: In **Maharashtra,** India, drones help sugarcane farmers detect fungal infections early, reducing crop losses.

2. Smart Irrigation Systems

Water scarcity is one of agriculture's most pressing challenges, particularly in arid and semi-arid regions. Smart irrigation systems tackle this by using sensors that monitor soil moisture in real time and automate water delivery based on actual crop needs. These systems minimize water waste, prevent overwatering, and ensure optimal plant hydration leading to healthier crops and lower water bills. Smart irrigation is not only water-efficient but also energy-saving, as it reduces the need for frequent pump operation.

Example: In **Israel,** a global leader in precision irrigation, **smart drip irrigation** allows farmers to grow crops like tomatoes and avocados in **desert areas**, using up to **50% less water** than conventional methods.

3. AI-Based Advisory Platforms

Artificial intelligence is revolutionizing agricultural decision-making through mobile-based advisory platforms. These platforms analyze data from satellites, weather forecasts, and on-field sensors to provide personalized recommendations to farmers. From crop planning and disease diagnosis to pest control and market forecasting, AI platforms offer real-time, location-specific guidance. This is especially valuable for smallholders in remote areas who may lack regular access to agricultural extension officers.

Example: *Plantix*, a mobile app, helps small farmers in Asia identify crop diseases through photos and recommends treatments.

4. **Soil & Climate Sensors**

On-ground sensors are vital tools in smart farming, offering detailed insights into soil conditions and local climate patterns. Soil sensors measure moisture levels, pH, and nutrient availability, enabling precise fertilizer and water application. Climate sensors, on the other hand, monitor temperature, humidity, rainfall, and wind, helping farmers anticipate and prepare for weather extremes like frost, droughts or storms. Together, these sensors create a real-time picture of field conditions that guides timely interventions and supports climate-resilient practices.

Example: In the U.S., precision farming tools by companies like *John Deere* enable targeted fertilizer spraying.

Economic and Social Benefits

Smart farming goes beyond just crops and technology, it directly impacts people and livelihoods.

Economic Impact:

Smart farming extends far beyond improving how crops are grown, it brings tangible economic and social benefits that uplift entire communities. By integrating digital tools like soil sensors, AI advisories, and mobile apps, farmers can reduce input costs through more efficient use of water, fertilizers, and pesticides. This not only helps in conserving valuable resources but also results in higher crop quality and yields. With real-time field monitoring and data-driven decisions, agriculture becomes more predictable, less risky, and significantly more profitable.

Economically, smart farming has proven to increase farmers' incomes by optimizing inputs and reducing losses. Precision agriculture allows for targeted application of fertilizers and pest control, cutting operational costs while maximizing productivity. Moreover, the data generated by these technologies such as yield forecasts, weather tracking, and soil analysis can be used as digital proof of performance. This helps farmers, especially smallholders, access formal credit, crop insurance, and government subsidies more easily, as financial institutions gain more confidence in lending based on verified field data.

Social Impact:

Socially, smart farming is helping reshape the rural labor landscape. Young people, once disinterested in traditional farming, are increasingly drawn to agri-tech startups and digital platforms that offer modern, skill-based career paths in agriculture. At the same time, user-friendly mobile apps and simplified machinery are enabling more women to actively participate in farm management. By reducing the physical burden of tasks and providing timely information, technology levels the playing field in a sector historically dominated by men. Additionally, the increase in food availability and diversity brought about by higher yields contributes to better nutrition, particularly in remote and underserved areas.

A powerful example of this can be seen in Rwanda, where the e-Soko mobile platform empowers women farmers by giving them access to current market prices and direct buyer contacts. With better bargaining power and improved market access, these women are not only increasing their incomes but also gaining a stronger voice in their households and communities. In essence, smart farming is not just a tool for agricultural improvement. It is a vehicle for inclusive rural development and global socio-economic advancement.

Challenges and Limitations

Despite its promise, smart farming faces significant challenges, particularly in low- and middle-income countries.

Key Barriers:

- ✓ **High Initial Investment:** Equipment and installation costs deter smallholder farmers.
- ✓ **Limited Digital Literacy:** Many rural farmers are unfamiliar with using smartphones, apps, or online platforms.
- ✓ **Connectivity Gaps:** Lack of internet access in remote areas limits the effectiveness of digital tools.
- ✓ **Fragmented Land Holdings:** Small farm sizes make adoption of certain technologies less viable.
- ✓ **Data Privacy Issues:** Farmers may be reluctant to share data with private firms or governments.

Potential Solutions:

- ✓ **Government Subsidies and Training Programs:** Help farmers adopt technology and build skills.
- ✓ **Public-Private Partnerships:** Encourage collaboration to develop affordable and accessible solutions.
- ✓ **Localization of Technology:** Tools must be designed to suit the local language, crops, and culture.
- ✓ **Cooperative Models:** Group-based adoption of technology can reduce costs and build collective capacity.

Unless these challenges are addressed, the benefits of smart farming may remain concentrated among wealthier or large-scale farmers, widening the rural divide. Bridging this **digital gap** is essential for equitable global development.

The Future of Smart Farming As technology evolves, the future of smart farming looks even more promising and necessary.

Emerging Trends:

- ✓ **Blockchain** for food traceability and transparency in supply chains
- ✓ **AI-powered robots** for selective harvesting and real-time crop care
- ✓ **5G connectivity** enabling real-time data sharing across rural farms
- ✓ **Vertical farming** and **urban agriculture** redefining how cities grow food

Collaborative Growth:

- ✓ Governments must invest in digital infrastructure and farmer education.
- ✓ NGOs and civil society can build awareness and promote inclusive access.
- ✓ Tech startups and agribusinesses can design scalable, farmer-friendly innovations.

The fusion of agriculture and technology will shape the **next green revolution** not with more land or water, but with **more knowledge and connectivity.** Smart farming has the power to not only feed the world, but also **empower** it.

Conclusion

Feeding the future requires more than producing more food, and it demands a smarter, fairer, and more sustainable way of farming. Smart farming, with its technology-driven solutions, offers a pathway to address hunger, poverty, and environmental degradation, all while empowering farmers and rural communities. By aligning with global development goals, enhancing productivity, and fostering innovation, smart farming plays a pivotal role in shaping a resilient agricultural future. However, its potential can only be realized if we ensure access for all, especially smallholders, women, and marginalized communities.

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Enhancing Guava Productivity: The Role of Awareness in Crop Regulation Adoption

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Guava (*Psidium guajava* L.) is one of the most important tropical and subtropical fruit crops in India. Known for its high nutritive value, hardy nature, and year-round fruiting potential, guava is widely cultivated by small and marginal farmers. However, productivity remains suboptimal in many areas due to traditional practices and irregular flowering and fruiting patterns. Guava also referred to as the "Apple of the Tropics" or the poor man's apple. It is a crop that originated in tropical America and stretches from Mexico to Peru. Over time, its hardiness, abundant yield, high vitamin C content, fair amount of calcium content, and high remuneration even in the absence of much care have made it a commercially significant crop in several countries. It is possible to consume guava fruits raw or processed.

Crop regulation is a scientific approach involving pruning, irrigation control, and nutrient management and has emerged as a promising strategy to standardize flowering and improve yield and fruit quality. Yet, its success largely depends on the level of awareness and adoption among farmers. Crop regulation in guava primarily refers to practices such as pruning, irrigation control, use of plant growth regulators (PGRs), and flower thinning to manipulate the timing and abundance of flowering and fruiting.

Understanding Crop Regulation in Guava

Guava typically flowers and fruits in three distinct seasons: spring (Ambe bahar), rainy (Mrig bahar), and winter (Hasth bahar). Among these, the winter crop is most desirable due to its superior fruit quality, minimal pest incidence, and higher market demand. Conversely, the rainy season crop often suffers from fruit fly infestation, low sugar content, and poor shelf life, making it less profitable. Crop regulation aims to suppress the less desirable flowering seasons (especially the rainy season) and encourage a concentrated harvest during the optimal winter season. Common crop regulation techniques include:

- Deblossoming or thinning
- Bending of shoots
- Shoot pruning
- Withholding irrigation and fertilizers
- Chemical treatments (e.g., application of NAA or urea sprays)
- Root exposure and root pruning

By adopting crop regulation practices like root exposure, withholding irrigation, and selective pruning, farmers can suppress the unwanted rainy season crop and concentrate growth for the more profitable winter crop.

1. **Deblossoming or Thinning**: Different chemicals induced the rainy season crop to deblossom, resulting in an increase in the winter season crop. Spray urea, naphthalene acetic acid (NAA), potassium iodide, and other horticultural chemicals at varying concentrations on guava, citrus, pomegranate, and other crops to deblossom them. Deblossoming can be done manually as well. By deblossoming or thinning the trees in April May blossoms, the trees can generate abundant flowering in June-July and fruit harvesting in November-February.

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Growth regulators and certain compounds have been proven to be particularly successful in floral thinning and cropping season manipulation.

2. **Bending of shoot**: Shoot bending is one of the ways to produce better quality fruits in the off-season of guava. In case of bending of branch wood tension of branch is increased and phloem formation decreased. As a result photosynthetic product pass slowly from the shoots of bent branch as to the other parts, maintaining increased C: N ratio and induce more flowering and fruit set. Bending forced dormant reproductive buds into growth. The upright branch produces fewer flowers and fruits than the bent branch. Bending induces profuse flowering and fruiting, as well as fetches greater returns.

3. **Shoot pruning**: is one of the most effective methods, involving the removal of old or unproductive branches to stimulate the growth of new vegetative and floral shoots. This practice not only enhances air circulation and reduces pest incidence but also promotes uniform flowering and larger, better-quality fruits.

4. **Withholding of irrigation**: Withholding irrigation after harvesting the winter crop of guava in the northern plains causes the tree to shed its blooms and go dormant. June sees the application of well-balanced manure and fertiliser, as well as irrigation. The tree bloomed profusely after around 20-25 days, and the fruit matured throughout the winter. It has been suggested that water stress be induced by withholding irrigation from December to June or until the beginning of the monsoon season, depending on the prevailing conditions
5. **Chemical treatments**: Application of plant growth regulators (PGRs), such as Naphthaleneacetic acid (NAA), ethrel (ethephon), Urea and 2, 4-D. These chemicals are used for thinning or deblossoming the rainy season crop to encourage flowering during the more profitable winter season. Chemical thinning is particularly effective and economical for large-scale orchards.

6. **Nutrient application** plays a vital role in supporting vigorous growth and quality fruit development. Balanced doses of macronutrients like nitrogen, phosphorus, and potassium, along with essential micronutrients such as zinc, boron, and magnesium, are applied through soil or foliar sprays to enhance flower retention and fruit quality.

7. **Root exposure and root pruning**: The plant's roots are exposed to the sun by removing up to 7 -10 cm of soil from a 40-60 cm radius around the tree trunk. Before blossoming, the water is withheld for a month or two. Leaves wilt and fall to the ground as a result of water stress. Roots are covered with a mixture of soil and FYM and irrigated right before one month of targeted bahar blossoming begins. Irrigations are administered at appropriate intervals after that. As a result, plants produce fresh vegetative growth, abundant flowering, and fruiting.

Why Awareness Matters:

Despite its proven benefits, crop regulation remains underutilized, especially among smallholder farmers. This gap is primarily due to a lack of awareness and technical knowledge. Farmers who are unaware of the benefits or lack the training to implement crop regulation may continue traditional methods, leading to inconsistent yield and income. Awareness programs serve as a bridge between research institutions and field-level implementation. Through demonstrations, field days, and training workshops, farmers learn not only the *what* and *why* of crop regulation, but also the *how*—tailoring techniques to local conditions and resources.

Project Highlights: Farmer Engagement and Learning

A recent project aimed at enhancing guava productivity through awareness and adoption of crop regulation techniques showed encouraging outcomes. The initiative involved:

- Conducting baseline surveys to assess farmer knowledge
- Organizing field demonstrations of crop regulation techniques
- Disseminating information through leaflets, posters, and farmer meetings
- Providing follow-up support for field-level implementation

Results indicated a significant improvement in farmer understanding of crop regulation and a measurable increase in the adoption of recommended practices. Farmers reported improved flowering synchronization, better fruit quality, and a rise in marketable yield, especially in the winter season.

Benefits of Awareness-Driven Crop Regulation

1. **Higher Yields**: Regulated flowering leads to a concentrated harvest with uniform fruit size and better quality.
2. **Improved Income**: Off-season production fetches better prices in the market, increasing profitability.
3. **Pest and Disease Management**: Reducing the rainy season crop limits exposure to fruit flies and other pests.

Demonstrations of Crop Regulation Techniques

4. **Resource Optimization**: Better planning of irrigation, nutrients, and labor based on crop cycle.
5. **Sustainable Farming**: Promotes scientific, eco-friendly practices that preserve soil and plant health.

The response of farmers to the project:

The response of farmers to the project **"Enhancing Farmer Income through Guava Crop Regulation"** has been overwhelmingly positive, with a high adoption rate and clear recognition of the benefits of crop regulation in improving guava yield and income. The shift to regulated winter cropping enabled them to harvest larger, sweeter fruits during high-demand periods, resulting in better market prices—often double compared to traditional rainy-season harvests. Farmers also noted reduced pest and disease incidence, lower post-harvest losses, and more efficient use of labor due to synchronized fruiting. While some farmers initially expressed hesitation due to lack of technical knowledge, hands-on training and field demonstrations greatly improved their confidence and adoption rates.. Overall, the project significantly boosted farmer morale, proving that guava crop regulation is not only agronomically sound but economically transformative.

Challenges and the Way Forward

While awareness campaigns are effective, challenges like lack of access to inputs, labor shortages, and climatic variability still hinder full-scale adoption. To address these, extension services must be strengthened, local success stories should be showcased, and technology should be made more accessible through mobile apps and farmer networks.

Additionally, convergence with government schemes and Krishi Vigyan Kendras (KVKs) can play a crucial role in scaling awareness and adoption.

Conclusion

Enhancing guava productivity is not just about introducing new techniques—it's about empowering farmers with the knowledge to use them effectively. Awareness and education around crop regulation are key to unlocking the yield and income potential of guava farming. By investing in farmer training and support, we can ensure that scientific innovations reach the ground level, benefitting both growers and the larger horticulture economy. Empowered with scientific knowledge and field-based guidance, guava farmers can not only increase yields and profits but also contribute to a more sustainable and efficient horticulture system. Investing in awareness today ensures resilient productivity tomorrow.

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Growing Upwards: Managing Soils in Urban Gardens and Green Roof Agriculture

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As urban areas expand vertically and land becomes limited, rooftop farms and urban gardens are emerging as effective means to cultivate fresh produce and enhance concrete environments. However, the primary challenge is not above the ground, but below it: managing soil in areas not originally designed for agriculture. This article explores the concealed realm of urban soil management, revealing how city gardeners tackle issues such as contamination, poor fertility, compaction, and limited soil depth. From creating unique soil mixtures and utilizing compost effectively to selecting appropriate lightweight media for green roofs, we investigate practical and sustainable methods to transform barren environments into flourishing edible ecosystems. Whether it's an herb garden on a balcony or a vegetable patch on a rooftop, healthy soil is essential for cultivating vertical cityscapes while rejuvenating urban settings.

Keywords: Urban garden, rooftop garden, soil health, nutrient, management

Introduction

As cities rise higher and agricultural land diminishes under concrete, a quiet shift is taking place on rooftops, overhangs, and vacant lots. Urban agriculture once considered a marginal concept is becoming a significant contributor to food security, climate resilience, and healthier urban living. However, while growers and raised beds attract attention, the true unsung hero of urban farming lies below the surface: the soil. Managing soil in urban areas involves more than just adding compost and planting seeds. Urban soils encounter a distinct array of challenges are pollution, compaction, low fertility, and limited depth. Nevertheless, with the right techniques, even the most lifeless urban soil can be transformed into a productive medium for food cultivation. In cities that are overcrowded, with minimal land available and rising food insecurity, rooftops, balconies, and neglected spaces in urban settings are evolving. A novel form of agriculture is flourishing one that grows vertically rather than horizontally. From lettuce on rooftops in New York to tomatoes in terrace gardens in Mumbai, urban agriculture is becoming a foundational aspect of sustainable city living. Yet, one crucial factor often goes unnoticed beneath all the greenery: the soil. Or more commonly in urban environments, the absence of it.

What Makes Urban Soils Unique and Challenging

Unlike the fertile, rich soils typically found in conventional farmland, urban soils face a unique set of difficulties that can impede successful growth. These soils are frequently compacted due to extensive construction activities, shallow or entirely absent in rooftop areas, and often contaminated with heavy metals, industrial chemicals, or petroleum byproducts. Furthermore, they usually lack nutrients or present extreme pH levels, rendering them unsuitable for thriving plant development. Consequently, many rooftops or balcony farms forgo native soils entirely and turn to specially designed growing mediums. While this method introduces additional challenges, it also allows for innovative soil management techniques specifically developed for urban agriculture.

Contamination: Hidden Yet Hazardous

Numerous urban areas, especially those situated in older districts or previous industrial areas, are

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frequently tainted with harmful substances. Pollutants like lead, arsenic, and other heavy metals can linger in the soil for many years, presenting serious threats to human health if they infiltrate the food chain through consumable crops. To promote secure urban farming, it is crucial to initially examine the soil utilizing budget-friendly testing kits or laboratory assessments to identify any toxic elements. If contamination is detected, one of the safest approaches is to utilize raised beds or containers filled with uncontaminated, imported growing media. In locations where soil safety is uncertain, it's advisable to cultivate only ornamental plants or non-edibles such as flowers and specific herbs, while reserving food production for areas with confirmed clean soil. Furthermore, methods like phytoremediation, growing species like sunflowers, mustard, or vetiver can assist in gradually extracting and diminishing harmful contaminants in the soil over time.

Creating Your Own Soil in the Urban Environment

As many urban soils are inadequate for cultivation due to poor structure or contamination, urban gardeners often create their own tailored soil mixtures to promote healthy plant growth. A commonly utilized blend for rooftop vegetable beds generally consists of 40% compost to provide vital nutrients, 30% cocopeat or peat moss for efficient water retention, 20% sand or perlite to ensure adequate drainage, and 10% vermicompost or well-rotted organic manure to introduce beneficial microbes and increase biological activity. This well-balanced mixture is not only lightweight and manageable but also well-drained and nutrient-rich making it perfect for containers, raised beds, and terrace gardens in urban farming systems.

The Living Soil: Remember the Microbes

Healthy soil is not merely a passive medium for supporting plants it is a vibrant ecosystem full of life. Beneficial microbes, fungi like mycorrhizae, and earthworms are crucial in assisting plants to absorb nutrients more effectively, resist disease, and grow stronger. To support and enhance this living soil community, urban farmers can implement several key practices. Introducing biofertilizers or microbial teas brings helpful microorganisms that enhance soil health and plant resilience. Applying organic mulches helps maintain soil moisture, thereby fostering a conducive environment for microbial activity. It's also vital to steer clear of chemical pesticides, as they can disrupt or eliminate beneficial soil organisms. Moreover, rotating crops throughout the seasons helps sustain soil biodiversity, preventing pest population and promoting a balanced, healthy soil food web.

Water Management in Urban Farming

Urban soils, particularly those employed in rooftop gardens, tend to dry out rapidly due to their shallow depth, constant exposure to sunlight, and drying influence of wind. This renders effective water management essential for supporting healthy plant growth in urban area. One successful approach is to apply organic mulch such as dried leaves, rice husk, or straw which aids in moisture retention by minimizing evaporation and insulating the soil. Installing drip irrigation systems or utilizing self-watering containers can guarantee consistent hydration while saving water. For rooftop gardens, integrating hydrogels or water-retaining crystals into the soil blend can substantially enhance moisture retention. Additionally, incorporating vermicompost not only enriches the soil with nutrients but also improves its ability to hold water, creating a more stable environment for plant roots.

Nutrient Cycles in Small Spaces

In compact urban gardens, managing nutrients is both crucial and sensitive. Gardeners typically rely on organic materials such as kitchen waste compost, cow manure, poultry litter, and vermicompost, all of which offer high-quality, slow-release nutrients that foster plant development. However, in restricted spaces with limited soil depth, over-fertilization can rapidly create issues. Surplus nutrients, particularly salts, can build up in the soil and harm plant roots, leading to decreased productivity and soil health. To avoid this, it is vital to apply organic fertilizers sparingly, ensuring that nutrients are introduced only as necessary. Adding biochar to the soil can assist in retaining nutrients and minimizing leaching, particularly during watering. Regularly flushing containers with plain water can also help eliminate excess salts. Furthermore, implementing crop rotation and cultivating nitrogen-fixing legumes like beans or peas can naturally replenish soil fertility and sustain a balanced nutrient cycle in gardens with limited space.

Rooftop Farming: Engineering Considerations

For those growing food on rooftops, ensuring structural safety and careful design is paramount. It is important to evaluate the rooftop's load-bearing capacity, as the total weight of soil, water, and plants can be significant. To alleviate the load on structures, gardeners should utilize modular containers or lightweight growing media that are specifically tailored for rooftop use. Proper drainage layers are equally essential to prevent water accumulation and damage, as well as root barriers to hinder aggressive roots from penetrating the roof surface. The growing media commonly used for green roofs includes materials like expanded clay, vermiculite, or pumice for aeration and drainage, combined with coconut coir, compost, or other lightweight soils for moisture retention and nutrient provision. Additionally, geotextile mats are frequently placed between layers to filter particles and bolster the overall structure. With careful planning, rooftop gardens not only promote flourishing crop production but also safeguard and enhance the building itself.

Composting: Closing the Loop

Urban gardeners can conveniently convert everyday kitchen waste into nutrient-dense compost commonly known as "soil gold" using straight forward, space-efficient methods. By utilizing small compost bins, even apartment dwellers can recycle vegetable peels, fruit scraps, and coffee grounds into valuable organic matter. For more confined spaces like balconies or beneath sinks, vermicomposting with earthworms provides an effective and odourless method for breaking down waste into high-quality compost. To keep a healthy composting environment and prevent unpleasant odours, it is essential to combine wet, green waste with dry materials such as shredded newspapers, dried leaves, or cardboard. This balance of carbon to nitrogen promotes quicker decomposition and results in a crumbly, nutrient-rich amendment that enhances soil structure, retains moisture, and naturally enriches urban garden beds.

Real-Life Inspiration

Urban farming is flourishing worldwide, with creative soil management methods facilitating productive agriculture in unexpected locations. In Singapore, the Edible Garden City project has turned hotel rooftops, shopping malls, and school grounds into vibrant food gardens by utilizing lightweight soil mixtures infused with organic compost transforming underused areas into lively food production centers. In Nairobi, particularly in the crowded slums of Kibera, local cultivators grow nutritious crops such as spinach and kale in vertical sacks filled with homemade compost, showcasing how poor or contaminated soils can be rejuvenated through affordable organic materials. Meanwhile, in New York City, the Brooklyn Grange one of the largest rooftop farms globally covers more than two acres and yields thousands of kilograms of vegetables each year. It employs specially designed green roof soil mixes, efficient drip irrigation systems, and compost-based fertilization to sustain soil health and productivity, demonstrating that with the appropriate methods, even rooftops can serve as fertile farmland.

Conclusion

Soil management in urban agriculture encompasses more than just cultivation it's about restoration. It transforms barren areas into flourishing ecosystems. Whether it's a bag of soil on a balcony or an expansive green roof, robust soil is essential for vibrant cities. Therefore, the next time you Savor a city-grown tomato, keep in mind: the foundations of the future lie right beneath us, even if that soil is three stories up.

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Economic and Agronomic Benefits of Intercropping in Coconut Farms

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Introduction

Coconut farming holds a prominent place in tropical agriculture, especially in India, Sri Lanka, the Philippines, and Indonesia. Despite its economic importance, coconut cultivation often faces the challenge of low returns due to long gestation periods, price fluctuations, and monocropping inefficiencies. The traditional system of planting coconut with wide spacing (7.5m × 7.5m or more) leaves vast land areas underutilized.

Intercropping—growing compatible crops between or alongside coconut palms—is a practical and sustainable solution. It offers significant economic and agronomic advantages by enhancing resource use, improving soil health, and providing an additional income stream for farmers. This article explores these benefits in detail.

Economic Benefits of Intercropping in Coconut Farms

1. Enhanced Income Generation

Intercropping ensures that farmers do not rely solely on coconut yield and prices. Fast-growing intercrops such as banana, pineapple, turmeric, ginger, and pulses start yielding within a few months, offering early and regular returns. This dual-income system helps small and marginal farmers achieve economic stability.

2. Better Resource Utilization

Intercrops make use of sunlight, water, and soil nutrients that might otherwise go wasted in monocropped coconut plantations. This increases overall productivity per unit area, maximizing return on investment.

3. Reduced Production Costs

Some intercrops, especially legumes, improve soil fertility naturally and reduce the need for external inputs like fertilizers. Additionally, intercrops suppress weeds, reducing weeding costs. Shared use of farm inputs (water, manure, labor) across multiple crops also brings down overall costs.

4. Risk Mitigation

Intercropping minimizes the risk of complete crop failure. If one crop suffers due to pests, diseases, or climatic conditions, the other may still provide income. This diversified cropping approach reduces dependence on a single commodity.

5. Market Opportunities

Some high-value intercrops such as pepper, medicinal plants, and spices have significant demand in local and export markets. Proper planning can turn coconut gardens into commercially viable multi-crop systems.

Agronomic Benefits of Intercropping

1. Improved Soil Fertility

Leguminous intercrops such as cowpea, greengram, and groundnut fix atmospheric nitrogen in the soil, enriching it for the main crop. The addition of organic matter from intercrop residues further improves soil structure and microbial activity.

2. Efficient Use of Resources

Coconut roots explore deeper soil layers while most intercrops utilize the topsoil. This complementary rooting system ensures efficient use of soil nutrients and moisture, reducing wastage and improving yield.

3. Pest and Disease Control

Crop diversity helps in managing pests and diseases naturally. Certain intercrops act as trap crops or natural repellents, disrupting pest life cycles and reducing chemical pesticide use.

4. Reduced Soil Erosion

Intercrops cover the soil surface and protect it from erosion due to wind or rain. They also reduce water runoff and improve water infiltration.

5. Enhanced Biodiversity

Introducing different species within coconut plantations encourages beneficial insects, birds, and soil organisms. This leads to a more balanced and resilient agroecosystem.

Common Intercropping Combinations in Coconut Farms

Intercrop Category	Examples
Short-term crops	Cowpea, greengram, blackgram, vegetables
Medium-term crops	Banana, pineapple, turmeric, ginger
Long-term crops	Pepper (on standards), cocoa, arecanut

The choice of intercrops depends on climatic conditions, soil type, market demand, and the age of the coconut trees. Young plantations are best suited for short-duration crops, while mature ones can support more permanent crops like cocoa or pepper.

Challenges in Intercropping Coconut Farms

While the advantages are many, certain challenges also exist:

While intercropping in coconut farms offers numerous benefits, it also presents certain challenges that require attention for successful implementation. One major concern is the competition for nutrients, water, and sunlight, especially when intercrops are not carefully selected or managed, which may affect the growth and yield of both the coconut palms and the intercrops. Additionally, intercropping systems often demand increased labor, monitoring, and more complex farm management compared to monocropping.

Farmers may also face challenges related to market dependency and price fluctuations for the intercrops, which can affect profitability. Moreover, the success of intercropping relies heavily on the farmer's technical knowledge, including understanding compatible crop combinations, seasonal planning, and integrated nutrient and pest management. These challenges, however, can be effectively addressed through scientific crop selection, proper planning, timely agronomic interventions, and capacity building for farmers through targeted training and agricultural extension services.

These challenges can be addressed through proper planning, scientific crop selection, and capacity building for farmers through extension services.

Recommendations for Successful Intercropping

For successful intercropping in coconut farms, it is essential to follow a set of well-planned agronomic and management practices. Farmers should begin by conducting soil testing to understand nutrient status and select intercrops accordingly. Choosing crops with complementary growth habits and root structures helps minimize competition and ensures efficient resource use. Proper spacing and balanced nutrient management are critical to support the healthy growth of both coconut palms and intercrops.

The use of organic mulches not only conserves soil moisture and suppresses weeds but also enhances soil health. Adopting integrated pest management (IPM) practices can effectively control pests while reducing dependency on chemical inputs. Lastly, maintaining accurate records of yields, input usage, and returns enables farmers to monitor performance, evaluate profitability, and make informed decisions for future cropping seasons.

Conclusion

Intercropping in coconut farms is not merely a space-filling technique but a transformative approach to sustainable agriculture. It significantly enhances the economic viability of coconut cultivation by offering diversified income sources, reducing production risks, and optimizing resource use. Agronomically, it strengthens the health of the farm ecosystem by

Table 1. Types of Intercrops in Coconut Gardens

Category	Examples of Intercrops	Suitable Stage of Coconut	Duration
Short-Duration/Seasonal Crops	Cowpea, Greengram, Blackgram, Redgram, Groundnut, Sesame, Okra, Tomato, Brinjal, Gourds	Young coconut (1–5 years)	2–6 months
Medium-Duration Crops	Banana, Papaya, Pineapple, Turmeric, Ginger, Napier Grass	Young to mid-age (3–10 years)	8 months – 2 years
Long-Duration/ Perennial Crops	Pepper, Cocoa, Arecanut, Guava, Sapota, Pomegranate	Mature coconut (10+ years)	3–15 years or more
Soil-Enriching Green Manures	Sunhemp, Daincha (Sesbania), Velvet bean (Mucuna)	All stages	2–4 months (not harvested)
Multi-tier/Integrated Cropping	Coconut + Pepper + Pineapple; Coconut + Banana + Fodder Grass; Coconut + Timber Species	Mature coconut (wide-spaced farms)	varies (system-dependent)

improving soil fertility, controlling erosion, managing pests naturally, and fostering biodiversity.

When thoughtfully planned and executed with compatible crops, intercropping turns coconut gardens into dynamic, productive, and climate-resilient systems. Moreover, it empowers farmers—especially smallholders—with improved livelihood security, better market opportunities, and long-term soil health. However, the success of intercropping depends on knowledge, training, and access to extension support.

By promoting scientifically guided intercropping models and farmer-friendly policies, we can unlock the full potential of coconut-based farming systems for a greener and more prosperous future.

References

Biddappa, C. C., & Srinivasa, K. (1994). Coconut-based cropping and farming systems. Indian Coconut Journal, 24(6), 2–6.

Devakumar, N., & Sathisha, G. (2016). Sustainable income through coconut-based integrated farming systems. International Journal of Agricultural Sciences, 8(60), 3371–3374.

Hegde, M. R., & Srinivas, K. (1991). Intercropping in coconut garden – A profitable venture. Indian Coconut Journal, 22(10), 3–6.

Maheswarappa, H. P., Hegde, M. R., Biddappa, C. C., & Dhanapal, R. (2000). Mixed farming of coconut with medicinal and aromatic plants – An overview. Indian Coconut Journal, 31(4), 8–12.

Nair, P. K. R. (1993). An introduction to agroforestry. Dordrecht: Kluwer Academic Publishers.

Nampoothiri, K. U. K., & Sairam, C. V. (1997). Coconut based farming system – A case study. Journal of Plantation Crops, 25(1), 83–85.

Patil, B. V., & Gholap, V. V. (2010). Economic analysis of intercropping systems in coconut orchard. Indian Journal of Agricultural Economics, 65(3), 482–487.

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Urban Horticulture and Vertical Farming: Sustainability for the Future

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The management of resources, environmental sustainability, and food security are all seriously threatened by India's fast urbanization. Urban horticulture and vertical farming have emerged as innovative solutions to these challenges, offering the potential to produce fresh food within urban settings while minimizing the environmental footprint.

Urban Horticulture: Cultivating Green Cities

Urban horticulture involves growing plants within city environments, encompassing community gardens, rooftop farms, and balcony planters. This practice not only provides fresh produce but also enhances urban aesthetics, improves air quality, and fosters community engagement. In cities like Singapore, community gardens have been instrumental in educating residents about nature and promoting sustainable practices.

Components of Urban Horticulture

Rooftop gardens: These are cultivated spaces on building rooftops that utilize containers or raised beds to grow vegetables, herbs, and ornamental plants, helping to reduce heat, manage rainwater, and enhance urban biodiversity.

Indoor farms: These are controlled-environment agricultural setups inside buildings that use technologies like hydroponics or LED lighting to grow crops year-round in limited spaces. (Figure 1)

Community gardens: These are shared urban spaces where individuals or groups collectively cultivate plants, fostering community engagement, promoting food security, and offering educational opportunities.

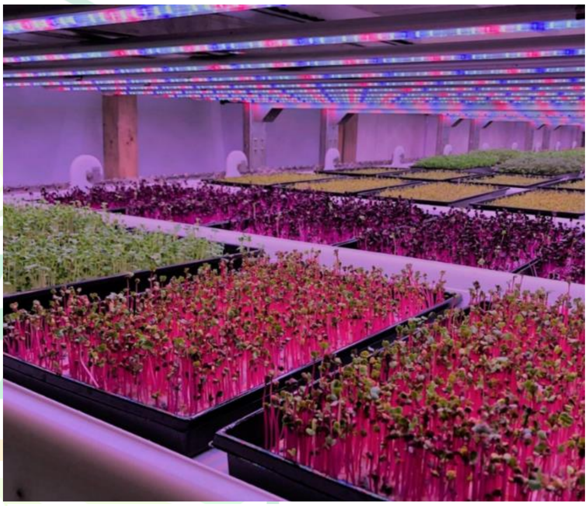

Figure 1. Indoor Farming with LED lights technology

Benefits

1. Reduced food miles:

Urban gardens help minimize the distance food travels from farm to plate, reducing transportation-related carbon emissions, lowering costs, and providing fresher produce to consumers.

2. Enhanced urban green spaces:

By converting rooftops, vacant lots, and community areas into gardens, cities become greener and more liveable, with improved air quality, reduced urban heat island effects, and increased opportunities for recreation and biodiversity.

3. Improved food security:
Urban agriculture increases local food availability, particularly in underserved or densely populated areas, helping communities become more resilient to food supply disruptions and promoting self-sufficiency.

Vertical Farming: Maximizing Space and Efficiency

Vertical farming takes urban agriculture a step further by cultivating crops in stacked layers within controlled environments. Utilizing hydroponic or aeroponic systems, these farms can produce higher yields with significantly less water and land compared to traditional farming methods.

Components of Vertical Farming

Hydroponics: This method involves growing crops by providing a suitable solution in place of soil. Plant roots are soaked in a solution in the growing tray that is monitored and circulated to maintain the correct chemistry.

Aeroponics: Plants grow in a soilless environment with little water or foggy soil. This system is very efficient, using 90% less water and 60% less fertilizer than hydroponic systems. Crop yield is increased from 45% to 75% and plants grow faster than other hydroponic systems.

Aquaponics: This technique combines aquaculture and hydroponics by using waste fish feed to grow plants in a shared space. Once installed, the system only requires weekly monitoring of pH and ammonia levels.

Controlled environmental agriculture (CEA): This usually occurs in an environmental structure such as a greenhouse or home. These zones allow controlling factors such as air quality, temperature, light, water use, humidity, carbon dioxide levels, and plant nutrients. Vertical farming setups often combine CEA with soilless growing techniques such as hydroponics, aquaponics, and aeroponics. Moreover, the components of vertical Farming are illustrated in Figure 2.

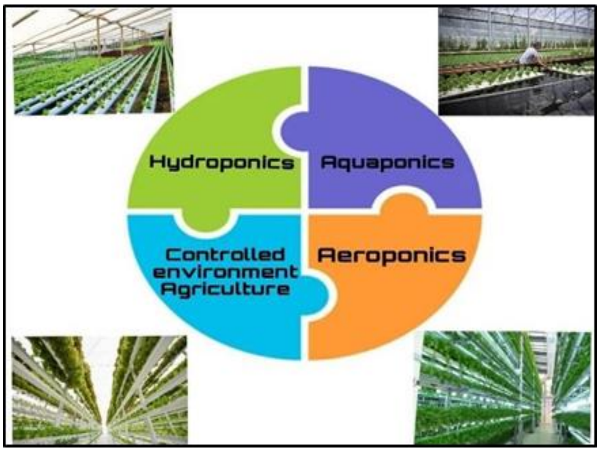

Figure 2. Components of Vertical Farming

Benefits:

1. Space Optimization: Vertical farms can be established in urban areas, utilizing unused spaces like warehouses or rooftops.

2. Resource Efficiency: These systems use up to 95% less water and eliminate the need for pesticides.

3. Year-Round Production: Controlled environments allow for continuous crop cultivation regardless of external weather conditions.

Key Challenges in the Adoption of Urban Horticulture and Vertical Farming:

1. High Initial Costs and Financial Viability:
The substantial capital investment required for setting up urban agriculture and vertical farming systems limits their widespread adoption, particularly in low-resource settings.

2. Perception and Acceptance Among Traditional Farming Communities:
Alternative farming methods are often met with scepticism or resistance by traditional agricultural communities, affecting their broader acceptance and integration into existing food systems.

3. Regulatory and Zoning Constraints:
Urban planning regulations, zoning laws, and building codes frequently pose significant barriers to establishing urban farms and vertical farming units within city environments.

Vertical farming companies in India

Presently, India hosts numerous indigenous vertical farming enterprises like Urban Kisaan, Clover, Living Food Company, Triton Food works, UGF (Urban Green Fate) Farms, and Barton Breeze.

Future Prospects

The integration of renewable energy, waste-to-resource systems, and precision farming is expected to enhance the efficiency of urban farming systems. Emerging concepts like edible architecture, modular farming units, and bio-integrated building designs are gaining traction.

Moreover, partnerships between urban planners, agricultural scientists, tech companies, and local communities are critical to creating scalable models. In India, for instance, the National Horticulture Mission is actively promoting rooftop gardens and hydroponic farming under urban renewal schemes.

Conclusion

Urban horticulture and vertical farming represent a paradigm shift in agricultural practice. A global analysis finds that urban agriculture could yield up to 10 percent of many food crops and offer transformative solutions to pressing challenges like food security, environmental sustainability, and efficient urban land use. Their wide-ranging benefits and capacity for innovation make them vital areas for continued research, policy support, and strategic investment which transformative potential for building climate-resilient and food-secure cities.

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Hybrid Breeding Strategies for Yield Enhancement in Major Cereal Crops

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Introduction

Global agriculture is under increasing pressure to feed a growing population while confronting challenges such as land degradation, climate change and limited natural resources. Cereals like rice, wheat, maize, sorghum and millets serve as staple foods for a majority of the world population. With limited opportunities to expand arable land, increasing crop yield through genetic improvements has become a critical focus. Hybrid breeding, a technique that exploits heterosis or hybrid vigor, has emerged as a powerful approach for enhancing yield potential and stability in cereal crops. The development and deployment of hybrid varieties have revolutionized agricultural productivity in several parts of the world. This paper explores hybrid breeding strategies, their applications in major cereal crops and their role in addressing the global food demand.

Principles of Hybrid Breeding

Hybrid breeding is based on the exploitation of heterosis, where the hybrid progeny outperforms its parents in traits such as yield, growth rate and resilience. This phenomenon arises due to the combination of genetically diverse parents, resulting in superior F1 hybrids. The success of hybrid breeding hinges on three key elements:

- **Genetic diversity**: A broad gene pool increases the likelihood of producing superior hybrids.
- **Inbred line development**: Stable, homozygous lines are required to produce consistent hybrid offspring.
- **Controlled pollination**: Ensures the desired crosses between selected parental lines.

  Hybrid breeding relies on careful selection of parental lines, understanding of combining ability, and precise pollination techniques to produce high-performing hybrid seeds.

Hybridization Techniques in Cereal Crops

Several techniques have been developed and refined to facilitate hybrid breeding in cereals:

1. **Manual Emasculation and Pollination**: Commonly used in self-pollinated crops like rice and wheat. Though labor-intensive, it allows precise crosses.
2. **Cytoplasmic Male Sterility (CMS)**: A maternally inherited trait where the female parent is male-sterile, eliminating the need for manual emasculation. Widely used in rice, maize, and sorghum.
3. **Genetic Male Sterility (GMS)**: Controlled by nuclear genes and requires roguing of fertile plants.
4. **Environment-Sensitive Genic Male Sterility (EGMS)**: Sterility is triggered by environmental factors such as temperature or photoperiod. Utilized in two-line hybrid systems.
5. **Biotechnological Tools**: Include doubled haploid technology for rapid inbred line development and molecular markers for identifying male sterile lines and fertility restorers.

Each technique has its advantages and limitations and the choice depends on the biology of the crop and resource availability.

Success Stories of Hybrid Varieties in Major Cereals

- **Hybrid Rice**: First commercialized in China in the 1970s, hybrid rice varieties have demonstrated 15-20% yield advantage over conventional varieties. India and Vietnam have also adopted hybrid rice with considerable success.
- **Hybrid Maize**: A pioneer in hybrid technology, hybrid maize was introduced in the USA in the 1930s. It is now widely grown globally, with hybrids contributing to significant yield gains.
- **Hybrid Sorghum and Pearl Millet**: India has seen major adoption of hybrid varieties in these dryland crops, leading to yield increases and improved livelihoods in arid regions.

Yield Enhancement through Hybrid Breeding

Hybrids have consistently shown yield superiority over open-pollinated varieties due to several factors:

1. **Vigor and Growth**: Enhanced photosynthetic efficiency and biomass accumulation.
2. **Resource Use Efficiency**: Better utilization of water, nutrients, and solar radiation.
3. **Stress Tolerance**: Greater resilience to biotic (pests, diseases) and abiotic (drought, heat) stresses.
4. **Uniformity**: Consistent growth and maturity facilitate mechanization and harvest planning.

The yield advantage of hybrids plays a crucial role in ensuring food security and improving agricultural sustainability.

Challenges and Limitations in Hybrid Breeding

Despite its advantages, hybrid breeding faces several challenges:

- **Seed Cost**: Hybrid seeds are expensive to produce and purchase due to the need for repeated production each season.
- **Seed Purity Maintenance**: Ensuring genetic purity during seed production requires stringent protocols.
- **Limited Adoption**: In crops like wheat and barley, the adoption of hybrid technology is limited due to biological constraints and economic considerations.
- **Infrastructure**: Hybrid seed production and distribution require robust infrastructure and trained personnel.

Addressing these challenges is essential for widespread adoption of hybrid technologies in cereals.

Advances in Molecular Tools for Hybrid Breeding

Modern molecular tools are enhancing the efficiency and precision of hybrid breeding:

- **Marker-Assisted Selection (MAS)**: Enables early selection of desirable traits and accelerates breeding cycles.
- **Genomic Selection (GS)**: Uses genome-wide markers to predict hybrid performance, increasing breeding efficiency.
- **CRISPR/Cas9 and Gene Editing**: Facilitates the development of male sterile lines and improves traits like drought tolerance and disease resistance.
- **Transcriptomics and Proteomics**: Provide insights into the molecular mechanisms underlying heterosis, guiding better parental selection.

These tools are revolutionizing hybrid breeding, making it faster, more accurate and cost-effective.

Future Prospects and Policy Support

To fully harness the benefits of hybrid breeding, the following areas need attention:

- **Climate-Resilient Hybrids**: Develop hybrids tailored to withstand changing climatic conditions.
- **Public-Private Partnerships**: Collaboration can drive innovation and ensure wider dissemination of hybrid seeds.
- **Capacity Building**: Training programs for seed producers, breeders and extension workers are vital.

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- **Policy Incentives**: Subsidies, crop insurance and regulatory frameworks to promote hybrid seed adoption.
- **Farmer Awareness**: Demonstrations and awareness campaigns to highlight the benefits of hybrid varieties.

Sustainable development of hybrid technology requires concerted efforts from all stakeholders.

Conclusion

Hybrid breeding strategies have proven to be a game-changer in enhancing the yield potential of major cereal crops. By exploiting heterosis, they offer a reliable means to address global food demands, improve farm incomes and promote resilience in agriculture. While challenges such as seed cost, infrastructure and adoption barriers exist, ongoing research and technological advancements are paving the way for broader application. With adequate policy support, public-private cooperation and farmer participation, hybrid breeding will continue to play a pivotal role in securing a food-secure future amidst the uncertainties of climate change and population growth.

Use of Remote Sensing and Drones in Crop Monitoring and Decision Making

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Introduction

The need for efficient and sustainable agricultural practices has become more pressing than ever due to the growing global population, changing climate patterns and limited natural resources. Traditional farming practices often rely on manual observation and delayed responses, leading to inefficient use of inputs and reduced productivity. In this context, the integration of modern technologies like remote sensing and drones offers a transformative approach to crop monitoring and decision-making. These tools provide real-time, precise and large-scale data, allowing farmers and agricultural professionals to make informed decisions that enhance crop health, yield and resource use efficiency. By capturing and analyzing data from the field in real-time, these technologies enable site-specific management, thus aligning with the principles of precision agriculture.

Concept and Working Principle

Remote sensing refers to the collection of data about an object or area from a distance, typically through satellite or aerial platforms. In agriculture, it involves capturing images or spectral data related to crop health, soil properties and environmental conditions. Drones, or Unmanned Aerial Vehicles (UAVs), equipped with sensors and cameras, can fly over fields to gather high-resolution data at frequent intervals. These UAVs can be equipped with various types of cameras and sensors, such as RGB cameras, multispectral sensors, hyperspectral sensors and thermal cameras.

These technologies operate based on the principle of detecting electromagnetic radiation reflected or emitted by objects. Different wavelengths of light (visible, infrared, etc.) are analyzed to assess various parameters like vegetation vigor, moisture content, and pest infestations. The data collected is processed using specialized software to generate actionable insights for farmers. Drones can fly at specific altitudes to capture targeted data, offering flexibility in monitoring crops at different growth stages. Remote sensing data can be time-series based, helping track crop development trends and anomalies over time.

Types of Remote Sensing Technologies

- **Satellite-Based Remote Sensing**: Utilizes satellites like Landsat, Sentinel, and MODIS to provide multi-spectral and temporal data. These systems cover vast areas and are suitable for regional and global analysis. While they offer consistent and long-term data, their spatial resolution may be lower compared to drone-based sensing and data acquisition can be affected by cloud cover.
- **Aerial Remote Sensing**: Involves data collection through manned aircraft or drones. It offers higher spatial resolution compared to satellites and is ideal for field-level monitoring. Drones provide a

cost-effective, accessible alternative to manned aircraft, especially for small to medium-sized farms.

- **Proximal Sensing**: Includes ground-based sensors and handheld devices used within the field to provide immediate and localized data. Tools such as handheld spectrometers, soil moisture sensors and chlorophyll meters fall under this category.

Each type of technology has its own advantages and limitations in terms of resolution, cost, frequency and accessibility. Integrating data from multiple sources (satellite, aerial and ground-based) can offer comprehensive insights for better decision-making.

Applications in Crop Monitoring

Remote sensing and drones have revolutionized how crops are monitored by enabling early detection and precise assessment. Key applications include:

- **Vegetation Indices**: Indices like NDVI (Normalized Difference Vegetation Index), SAVI (Soil-Adjusted Vegetation Index) and EVI (Enhanced Vegetation Index) help assess plant health, biomass and stress conditions. These indices are derived from reflected light in different spectral bands and can identify crop vigor and potential yield losses.
- **Disease and Pest Detection**: Changes in spectral reflectance patterns can indicate the presence of diseases or pests, enabling timely intervention. For example, a sudden drop in NDVI may suggest pest attack or disease spread, prompting targeted pesticide application.
- **Nutrient Deficiency Mapping**: Infrared and multispectral imaging can detect areas with nutrient stress, guiding site-specific fertilizer applications. For instance, yellowing of leaves detected in imagery can signal nitrogen deficiency, allowing for corrective measures.
- **Water Stress and Irrigation Management**: Thermal imaging identifies water-stressed zones by detecting temperature variations. Crops under water stress exhibit higher canopy temperatures, which can be visualized and corrected through efficient irrigation scheduling.
- **Growth Monitoring and Yield Prediction**: Continuous data helps track crop growth stages and predict yield with higher accuracy. By analyzing growth trends and vegetative cover over time, yield forecasting models can be developed.
- **Weed Detection**: Advanced algorithms can distinguish between crop and weed species based on spectral signatures, enabling precision weed control.

Data Integration and Decision-Making Tools

The raw data collected from remote sensing platforms is processed and analyzed using Geographic Information Systems (GIS), Artificial Intelligence (AI) and Decision Support Systems (DSS). These tools help in:

- **Creating Field Maps**: Visual representations of crop health, soil variability and pest hotspots. These maps are used for variable rate technology (VRT) operations, ensuring optimal input distribution.
- **Precision Agriculture**: Integrating data with GPS-enabled equipment for variable rate applications of seeds, fertilizers and pesticides. Precision farming enhances input efficiency and reduces production costs.
- **Real-Time Alerts**: Automated notifications for abnormal field conditions enable prompt action. For example, sudden temperature spikes or disease outbreaks detected through remote sensing can trigger instant alerts on mobile apps.
- **Farm Management Software**: Platforms like Climate FieldView, Trimble Ag and Ag Leader allow centralized data access and farm activity planning. These

platforms offer user-friendly interfaces, analytical tools and forecasting features.

- **Machine Learning Models**: AI-based models trained on historical and real-time data predict pest outbreaks, yield estimates and disease incidence, enhancing proactive management.

Advantages of Using Drones and Remote Sensing in Agriculture

- **Enhanced Monitoring Efficiency**: Large areas can be surveyed quickly and repeatedly with minimal labor. This is particularly useful during peak growing seasons or emergencies like disease outbreaks.
- **Improved Resource Use**: Targeted interventions reduce input waste and environmental impact. Site-specific nutrient and pesticide application minimizes runoff and pollution.
- **Increased Yields and Profitability**: Timely decision-making leads to better crop health and productivity. Healthy crops have higher market value and better storage quality.
- **Data-Driven Insights**: Historical and real-time data support long-term planning and risk mitigation. Farmers can analyze trends across seasons to improve cropping strategies.
- **Accessibility and Scalability**: Drones are increasingly affordable and suitable for farms of all sizes. Service-based drone operations make the technology accessible even to smallholder farmers.
- **Environmental Sustainability**: Precision application reduces greenhouse gas emissions and preserves biodiversity by minimizing chemical overuse.

Challenges and Limitations

Despite their advantages, there are certain challenges that hinder widespread adoption:

- **Cost and Technical Expertise**: Initial setup and maintenance costs can be high. Skilled personnel are needed for data analysis and interpretation. Training programs and subsidies can mitigate this barrier.
- **Regulatory Barriers**: Airspace regulations and licensing requirements vary across countries. Policy harmonization is essential to facilitate cross-border technology transfer.
- **Data Management**: Large volumes of data require robust storage and processing infrastructure. Cloud computing and edge computing are emerging as solutions.
- **Weather Dependence**: Cloud cover and extreme weather can affect image quality and drone operation. Integrating ground sensors can fill data gaps.
- **Connectivity Issues**: In remote areas, lack of internet connectivity can limit real-time data transfer and cloud-based analysis. Offline data collection and batch uploads can offer workarounds.
- **Privacy and Data Security**: Concerns regarding ownership and misuse of farm data need to be addressed through legal frameworks.

Future Prospects and Research Needs

- **AI and Machine Learning Integration**: Enhanced algorithms for better pattern recognition and predictive analytics. AI can also support real-time decision-making in autonomous farming systems.
- **Miniaturized Sensors**: Development of lighter, more energy-efficient sensors for broader applications. Nano-sensors and wearable plant sensors are on the horizon.
- **Blockchain and Data Security**: Ensuring transparency and ownership of farm data. Blockchain can create trust in agri-supply chains and traceability systems.
- **Policy and Subsidy Support**: Government schemes to promote adoption, especially among smallholder farmers. Investment in infrastructure and digital literacy is crucial.
- **Climate-Resilient Solutions**: Using remote sensing to develop adaptive strategies for climate change impacts, such

as identifying drought-prone areas and planning crop diversification.

- **Training and Education**: Building capacity among farmers and extension workers to understand and utilize these technologies. Integrating digital agriculture modules in agricultural curricula can bridge the knowledge gap.
- **Collaborative Research**: Partnerships between universities, private firms and farmer cooperatives can drive innovation and field-level validation.

Conclusion

Remote sensing and drones have emerged as game-changing tools in modern agriculture. Their ability to provide timely, accurate and actionable information significantly enhances crop monitoring and decision-making processes. By empowering farmers with real-time data, these technologies support efficient input use, minimize crop losses and improve profitability. While challenges exist in terms of cost, technical know-how and policy frameworks, the benefits far outweigh the drawbacks. With continued innovation, capacity building and supportive governance, these technologies can pave the way for a more sustainable, productive and resilient agricultural future. Their integration into farming systems represents a significant step toward achieving food security and environmental sustainability in the 21st century.

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Application of Genome Editing in Field Crops for Food Security

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Introduction

The global population is projected to exceed 9.7 billion by 2050, placing immense pressure on agriculture to produce more food using fewer resources. Climate change, soil degradation, pest outbreaks and diminishing arable land further compound this challenge. Field crops like wheat, rice, maize and pulses are staple sources of calories and nutrition for billions of people worldwide. In this scenario, advancing crop improvement technologies is vital to meet the growing demand for food.

Traditional breeding methods, though instrumental in past agricultural gains, are often time-consuming and imprecise. Genetic modification (GM) approaches have offered alternatives but are often met with regulatory and public resistance. Genome editing, particularly tools like CRISPR-Cas, has emerged as a game-changing technology, enabling precise, efficient and relatively low-cost alterations in crop genomes. This paper explores the application of genome editing in field crops to enhance food security, with emphasis on trait improvement, regulatory considerations and future prospects.

Overview of Genome Editing Technologies

Genome editing is a technique that allows scientists to make precise, targeted changes to the DNA of living organisms. The most widely used genome editing tools include:

- **CRISPR-Cas Systems:** Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR), paired with CRISPR-associated protein (Cas9 or Cas12), allows for specific and efficient editing of genes. It is simpler and more versatile than earlier technologies.
- **TALENs (Transcription Activator-Like Effector Nucleases):** These are engineered proteins that can cut DNA at specific sites. TALENs are known for their high specificity but are more complex to design.
- **ZFNs (Zinc Finger Nucleases):** ZFNs were among the first tools used for genome editing, using engineered zinc finger domains to target specific DNA sequences.

Compared to GMOs, genome editing often involves small, targeted changes without introducing foreign DNA, which makes it more acceptable in certain regulatory environments.

Target Traits for Improvement in Field Crops

Genome editing technologies are being employed to enhance various agronomic and nutritional traits in field crops:

- **Yield Potential and Stability:** Genes controlling flowering time, grain filling and plant architecture are being edited to increase productivity.
- **Drought and Heat Tolerance:** Key stress-responsive genes are modified to help plants survive under adverse climatic conditions.
- **Disease and Pest Resistance:** Genes associated with pathogen recognition and resistance (e.g., R genes) are edited to provide immunity against viral, fungal and bacterial infections.
- **Nutritional Enhancement (Biofortification):** Traits such as increased iron, zinc and vitamin A content are introduced to address micronutrient deficiencies.
- **Herbicide Tolerance and Abiotic Stress Resistance:** Editing of specific genes confers tolerance to herbicides, salinity and other abiotic stresses, facilitating crop management.

Applications in Major Field Crops

Wheat: Genome editing has been used to develop wheat with reduced gluten content, making it suitable for people with gluten sensitivities. Additionally, editing of genes like TaMLO has conferred resistance to powdery mildew.

Rice: CRISPR has been applied to improve disease resistance (e.g., bacterial blight by editing SWEET genes), increase drought tolerance and enhance grain size.

Maize: Gene editing targets include ARGOS8 for improved drought tolerance and editing of flowering time regulators to increase yield and adaptability.

Soybean: Modifications in fatty acid biosynthesis pathways have resulted in improved oil quality. Editing genes associated with virus resistance is also under active research.

Millets and Pulses: Though research is in early stages, genome editing is being explored to enhance nutritional quality and stress resilience in crops like finger millet and pigeon pea.

Regulatory Framework and Biosafety Concerns

Regulatory approaches to genome-edited crops vary globally:

- **India:** The Department of Biotechnology (DBT) has recently issued guidelines that differentiate genome-edited crops (without foreign DNA) from GMOs, potentially easing their path to commercialization.
- **United States:** The USDA does not regulate genome-edited crops that do not contain foreign DNA, allowing faster product development.
- **European Union:** Genome-edited crops are currently regulated under the same framework as GMOs, although revisions are under discussion.
- **Other Countries:** Japan, Argentina, Brazil and Australia have adopted progressive policies favoring genome editing.

Public acceptance remains a critical issue. Clear communication, safety assessments and ethical transparency are essential to build trust.

Challenges and Limitations

Despite its potential, genome editing faces several hurdles:

- **Off-Target Effects:** Although CRISPR is precise, unintended edits can occur, necessitating careful validation and safety assessment.
- **Technical Expertise and Infrastructure:** Developing and deploying edited crops require advanced molecular biology tools and trained personnel.
- **Regulatory Hurdles:** Inconsistent policies across countries can limit international collaboration and commercialization.
- **Public Perception:** Misinformation and ethical concerns can delay acceptance and adoption.
- **Intellectual Property (IP) Issues:** Access to CRISPR technology and related patents can be cost-prohibitive for small institutions or public-sector researchers.

Future Prospects and Research Priorities

The future of genome editing in agriculture is promising, with several exciting developments on the horizon:

- **Precision Editing:** Technologies like base editing and prime editing allow single-base changes without creating double-strand breaks, improving accuracy and reducing risk.
- **Minor and Neglected Crops:** Expanding genome editing to crops like millets, pulses, and oilseeds can diversify food sources and enhance resilience.
- **Integration with Digital Agriculture:** Combining genome editing with AI, big data and remote sensing can support data-driven breeding strategies.
- **Green Genome Editing:** Using biodegradable delivery systems and non-integrative methods to minimize environmental impact.

- **Policy and Capacity Building:** Investing in training, infrastructure and public-private partnerships to expand access and understanding.
- **Global Collaboration:** Harmonizing regulatory frameworks and promoting knowledge exchange can accelerate safe deployment.

Conclusion

Genome editing represents a transformative leap in crop improvement, offering precision, efficiency and versatility unmatched by traditional methods. In the face of mounting food security challenges, particularly in the developing world, it holds the key to developing crops that can withstand biotic and abiotic stresses, offer higher yields and meet nutritional needs. While challenges related to regulation, perception and equity persist, they are surmountable through thoughtful engagement, policy support and scientific rigor. With continued innovation and responsible deployment, genome editing can play a pivotal role in securing a sustainable and nutritious food future for all.

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Multifunctions and future prospects of endophytes and their metabolites in plant disease management

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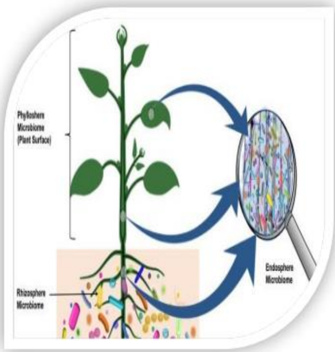
1. Introduction

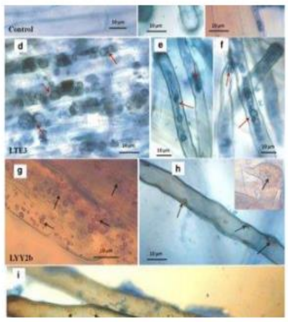
Plant diseases, are caused by pathogens, frequently cause crop losses and pose a serious risk to food security. When it comes to managing plant diseases, agrochemicals are effective. The widespread use of chemical pesticides and fertilizers, however, has detrimental impacts on both the environment and people, leading to ecological imbalance, pathogen resistance, and pollution. Unlike chemical approaches, biocontrols use natural control agents, including beneficial microbes and their metabolites, to operate in an environmentally favorable manner. The potential of endophytes and their bioactive metabolites as biological control agents (BCAs) has drawn a lot of attention.

Endophytes, which include endophytic fungi, endophytic bacteria, and endophytic actinomycetes, are found in a variety of plant organs, tissues, and intercellular spaces. They do not immediately cause disease symptoms. Long-term coevolution has allowed them to develop a mutually beneficial connection with their host plants. Both endophytes and plants depend on one another for nourishment and support, respectively. Endophytes within plants may have more direct and beneficial effects on plants due to their unique biological niches than soil microbes.

2. Endophytes

The word "Endophyte" is derived from two Greek words: "Endon," which means within, and "Phyton," which means plant. Within the host plant, endophytes are organisms that live as a symptomless colony, maybe for a portion of their life cycle (Stone et al., 2000). A plant and a microorganism can form a mutualistic relationship known as endophytism, in which the microbe lives inside the plant's tissues without producing any disease-related





symptoms.

3. Endophyte Diversity

3.1 Prokaryotic Endophytes

The database includes 23 recognized and candidate phyla of prokaryotic endophytes, including two from Archaea and 21 from Bacteria. Despite this astounding diversity, four bacterial phyla account for 54% of all endophytic prokaryotic sequences (7,348): Proteobacteria, 20% Actinobacteria, 16% Firmicutes, and 6% Bacteroidetes. The dominance of these phyla in the plant environment has also been documented. Gammaproteobacteria might be attributed to the majority of prokaryotic endophytes (26%). A few genera—*Pseudomonas*, *Enterobacter*, *Pantoea*, *Stenotrophomonas*, *Acinetobacter*, and *Serratia*—dominate the endophytic Gammaproteobacteria.

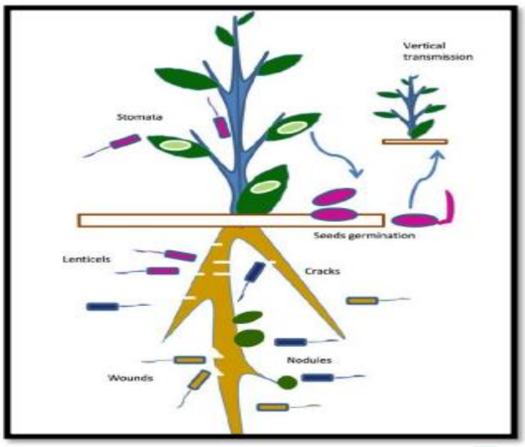
3.2 Eukaryotic Endophytes

Endophytes mainly belong to the Glomeromycota (40%), Ascomycota (31%), Basidiomycota (20%), unidentified phyla (8%), and, to a lesser extent, Zygomycota (0.1%) (Table 2). The phylum Glomeromycota only comprises endophytes known as arbuscular mycorrhizal fungi (AMF)

4. Entry and Transmission of Endophytes into Plant Tissue

4.1 Horizontal Transmission: Among individuals transmission is through soil, wind or insect vectors enter through cuts, wounds and natural openings like stomata E.g. *Epichloe* and *Neotyphodium*

4.2 Vertical Transmission: Directly from parent to offspring. Transmission is from generation to generation through infection of reproductive parts and seeds E.g. *Claviceps* spp.

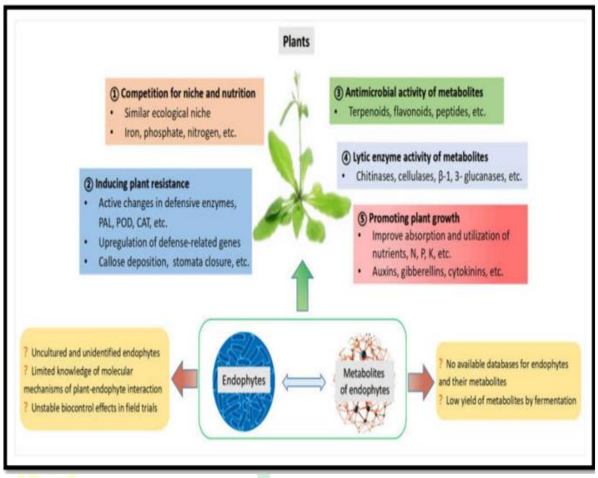


5. Multiple mechanisms employed by endophytes and their metabolites in plant disease management

Endophytes emit a variety of metabolites that directly or indirectly increase the host's tolerance to various stresses, making them advantageous to plants and potentially serving as promising biological agents in managing plant diseases.

5.1 MECHANISMS OF THE FUNGAL ENDOPHYTES

Fungal endophytic mechanisms in phytopathogen biological control. The expected mechanisms in the tripartite interaction between endophyte, host plant, and pathogen include direct inhibition of the pathogen by the endophyte through competition, antibiosis, or mycoparasitism, as well as indirect inhibition via resistance induction.



6. Antimicrobial Properties of Metabolites from Endophytes

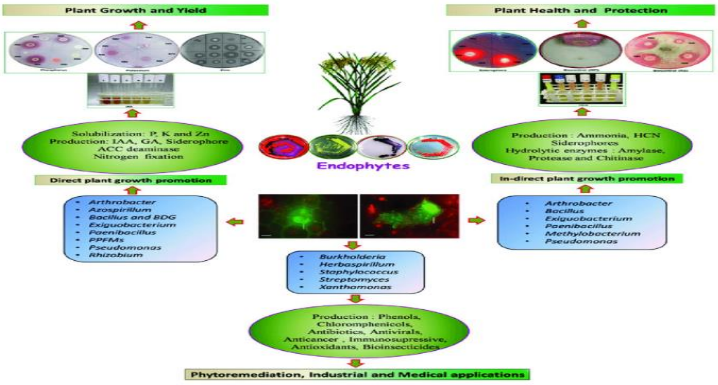
Endophytes are well-known for their ability to produce a wide number of secondary metabolites with antifungal and antibacterial characteristics that can directly inhibit pathogens.

7. Lytic enzyme activity of metabolites from endophytes

Endophytes are isolated from the host plant's seeds, roots, stems, leaves, or other tissues. They make enzymes like chitinases, cellulases, _-1, 3-glucanases, pectinases, glucanases, and proteases. These enzymes can destroy pathogens' cell walls or hinder spore germination.

8. Promotion of Plant Growth by Metabolites from Endophytes

Endophytic microbes can promote plant growth directly by fixing nitrogen, producing phytohormones (IAA and gibberellic acids), solubilizing phosphorus, potassium, and zinc, and producing siderophores, or indirectly by inducing pathogen resistance by producing ammonia, hydrogen cyanide, siderophores, lytic enzymes, and antibiotics. Endophytic microbes may boost plant growth by increasing germination rates, biomass, leaf area, chlorophyll content, nitrogen content, protein content, root and shoot length, yield, and tolerance to abiotic stresses such as drought, temperature, flooding, salt, pH, and so on.



9. Multi-Omics approaches for mining bioactive metabolites

With advances in high-throughput sequencing and systems biology, multi-omics, which include genomes, transcriptomics, proteomics, and metabolomics, are becoming increasingly important in plant-microbe interaction study. Genome analysis is vital for identifying and characterizing the genes involved in beneficial plant-endophyte interactions. It has identified the genes responsible for their colonization preferences inside plants, as well as the synthesis of numerous bioactive substances, such as genes for plant hormone and antibiotic production, nitrogen fixation, and nutrition acquisition (K, P, Fe, etc.). Proteomics is concerned with the examination of whole proteins from a tissue or organism under certain conditions.

10. Future Prospects

Research on plant disease resistance mechanisms and plant-microbe interactions has advanced dramatically during the last three decades. Endophytes, which colonize plant tissues, are thought to be natural agents in plant disease suppression. The creation of a diverse range of metabolites is largely responsible for their success. These metabolites have a wide range of biological functions, making them a prospective resource collection that is playing an increasingly essential role in a variety of sectors. Multi-omics joint analysis can achieve data complementation from genes to metabolites; consequently, it has been widely employed as a method for discovering physiological and molecular mechanisms in plant disease resistance. In this review, we discussed the various roles that endophytes and their metabolites play in plant biocontrol. The elicitation of plant resistance is one of the processes by which endophytes defend plants. Furthermore, numerous compounds produced by non-endophytic bacteria have been discovered as plant resistance elicitors. However, present research on endophyte metabolites in biological control focuses mostly on antibacterial, hydrolase, and growth-promoting properties, with few data on the induction of plant resistance. So we propose using multi-omics techniques to extract and discover more endophytic metabolites, particularly those that elicit plant resistance, in order to improve plant fitness and agricultural yields.

11. Conclusion

Biological control agents are effective and environmentally favorable in plant disease management, making them essential for sustainable agriculture. Endophytes and their metabolites offer numerous benefits over chemical pesticides and traditional bioformulations for plant protection. Plant endophyte metabolites contain a variety of bioactive chemicals that improve the host's defense against infections, as opposed to simply poisonous qualities. Thus, using one or more natural active compounds as the lead ingredient is one of the most promising approaches to green pesticide discovery in the future. However, there are significant hurdles that must be overcome before they can be produced and used on a wide basis.

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Reaping Success in Turmeric Cultivation – A Farmer Success Story

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Introduction

Chinnasalem, Kallakurichi and Rishivanthiyam blocks of Kallakurichi District offers great potential for large scale cultivation of Turmeric in an area of 2436 ha with a productivity of 34.5 q/ha. Th. P.Annamalai, is a Scheduled Caste farmer of Village V.Alambalam, Chinnasalem block cultivates Turmeric variety Nariyappanur since 2015. But he does not follow any seed rhizome treatment and Integrated Crop Management Practices. So, he obtained the fresh rhizome yield of 4.1 tonnes and dry rhizome yield of 820 kg per 0.4 ha area due to rhizome rot and improper management practices.

Plan, Implement and Support

Th. P. Annamalai underwent three training programmes related to Turmeric cultivation at KVK during 2022. After that, he adopted the following practices for turmeric cultivation *viz.*, selection of pest and disease free seed rhizome, each seed rhizome weighing 35 gms, seed rhizome treatment with *Trichoderma viridi* and *Bacillus subtilis* each @ 4gm/kg of seed rhizome for 20 minutes, soil test based fertilizer application, capsule form of IISR NPK and foliar spray of IISR Turmeric booster @ monthly intervals from three months after planting. Apart from theses frequent field visits and advisory services also made in different stages of the crop growth by KVK scientists. He also one of the partakers of FLD on Nutrient Management in Turmeric conducted during 2022 -23 & 2023-24.

Output

Every year he starts cultivation of Turmeric in the month of May. First of all, he satisfied with good sprouting percentage of turmeric (98%) in 35 DAS and crop establishment due to selection of quality seed rhizome and seed rhizome treatment with bio inputs. Then he obtained the highest yield of fresh (8.5 tonnes/0.4ha) as well as dried rhizome (1.7 tonnes/0.4ha) due to sustained release of capsule form of IISR NPK through drip irrigation at monthly intervals starting from one month after planting facilitated good crop growth. In addition, foliar spray of IISR Turmeric booster could effectively met micro nutrients requirement of the crop thus resulted in better development of mother corm with primary and secondary finger rhizome of 5-6 numbers/plant and yield of 242gm/plant.

Outcome

After primary processing, he sold the dried turmeric @ Rs.11000/quintal. For 17 quintal, he obtained the net income of Rs. 1,65,000/- in a crop duration of 8 months. Apart from yield enhancement and net income, the farmer could effectively reduce the fertilizer application and improve his soil fertility status with increased beneficial soil micro flora.

Impact

By seeing the success of his turmeric cultivation, 57 number of neighbouring farmers around his village confidently now doing the seed rhizome treatment with bio inputs, foliar spray of turmeric booster and soil test based fertilizer application. His yield improvement due to adoption of improved package of practices also intimated to Assistant Director of Horticulture and other officials from Department of Horticulture, Kallakurichi District during the field day held at V. Alambalam for further spread of this intervention.

Turmeric – One month after germination

Turmeric Rhizome Development Stage

Turmeric – Harvesting stage

Harvested Turmeric Rhizome

Harvested Turmeric Rhizome

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Broadbean: A Climate-Resilient Leguminous Crop for Sustainable Farming

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Introduction:

Broad bean (*Vicia Faba* L.) is a minor, cool season leguminous vegetable crop belonging to the Leguminosae family which is grown in Temperate and Sub Tropical regions of the world for its tender pods and seeds. It is commonly known as Faba bean, Bankla, horsebean and in Garhwal region, it is known as Syuchana. It is the only bean which which can be grown during winter season. It is extensively cultivated in China, Ethopia, Italy, France and Morocco. However, in India the cultivation of broad bean is not that much popular but grown in some States like Uttarakhand, Uttar Pradesh, Bihar and Madhya Pradesh etc. It is believed that the crop has its origin in Near East and Mediterranean Region.

Botany:

It is a annual plant with erect growth habit having a height ranging from 60 cm to 180 cm. These plants have erect stems, large and compound leaves and broad upright pods which borne on clusters in leaf axils. It is having a strong taproot system. The tender pods are light green and flowers are white in colour. The seeds are large and irregularly flattened. Generally, the pods are 5-8 cm long and 1-2 cm thick. It is self pollinated crop but some amount of cross pollination also occurs due to the insect activity.

Importance and Uses:

Broad bean is a rich source of vitamin C, protein and fibre. It also provides small amount of Vitamin B1 (Thiamine) and Vitamin B2 (Riboflavin). The pollen grains and green pods causes allergy to some peoples which turn in serious illness which is known as favism (Haemolytic anemia). It is also grown as cover crops and green manure crops as they are responsible for the nitrogen fixation in the soil due to the presence of nitrogen fixing bacteria. The plants are also used as livestock feed.

Soil and Climatic Requirements:

It can be grown on a wide variety of soils but well drained loam soils are considered best for its better growth and development. It requires a pH range of 6.5-7.5. it is cool season vegetable crop Seeds are generally sown on flat beds and raised beds. Usually the planting distance is 45 x 15 cm and 75 x 30 cm is kept during the cultivation. The seed rate generally varies from 70-100 kg/ha. The seed sowing is done during July-August and September- October. A light irrigation is given just after sowing of the crop. The crop requires light irrigation once in 7-10 days interval depending upon the requirement of the crop.

Nutrient Management:

Basal application of Farm yard manure is done @10-15 tonnes per ha was done at the time of field preparation. The crop requires a dose of N:P:K @ 20:50:40 kg/ha.

The crop requires two hand weeding at 20 and 40 DAS to make the field weed free during the crop growth period.

Harvesting and Yield:

The harvesting operation is carried out by plucking the green pods when they come at maturity. Generally the tender green pods are ready for harvesting after 3-4 months after sowing. The harvesting is done in short intervals as the tender pods do not come to maturity at same time. The average yield ranges from 5-10 tonnes/ha.

Pod Maturation Stage

Mature Tender Pods

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Green Consumerism: A Strategy to Restore the Environment?

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The increasing urgency of environmental degradation, driven by overconsumption, pollution, and unsustainable development, demands a revaluation of modern consumer habits. Green consumerism—where purchasing decisions prioritize environmental sustainability—has emerged as a potential lever for environmental restoration. This article explores the conceptual foundations, economic implications, psychological dynamics, and practical limitations of green consumerism. By examining empirical evidence, market trends, and policy frameworks, it evaluates whether green consumerism can serve as a viable environmental strategy or if it remains a partial solution in a broader systemic change.

1. Introduction

Environmental degradation—manifested through climate change, biodiversity loss, pollution, and resource depletion—has prompted global discourse on sustainable development. As consumer demand plays a pivotal role in driving production and, by extension, ecological footprints, shifting consumer behaviour has emerged as a potential intervention point. Green consumerism refers to environmentally conscious purchasing behaviours aimed at reducing environmental impact through sustainable products, services, and lifestyle choices (Sharma and Joshi, 2017). However, the question remains: Can green consumerism genuinely restore the environment, or does it merely offer a feel-good alternative to deeper systemic reform? There is requirement to critically examine the scope, potential, and limitations of green consumerism as a restorative strategy.

2. The Concept of Green Consumerism

Green consumerism promotes the idea that individuals can drive ecological change through conscious consumption. It involves buying products that are:

- Energy-efficient or low-carbon
- Recyclable or biodegradable
- Ethically sourced
- Free from harmful chemicals
- Produced with minimal environmental impact

This approach shifts responsibility from solely government and industry actors to individual consumers. Originating in the environmental movements of the 1960s and gaining momentum in the 1990s, green consumerism has evolved into a significant trend in modern marketplaces, underpinned by growing environmental awareness and global advocacy efforts.

3. The Psychological Drivers of Green Consumption

Psychological and behavioural factors heavily influence consumer decisions. Green consumerism is often driven by:

- *Environmental concern:* Consumers motivated by fears of ecological collapse.
- *Moral obligation:* A sense of ethical duty to minimize one's environmental impact.
- *Social identity:* Adoption of green habits as part of one's self-concept or social image.
- *Perceived efficacy:* The belief that individual actions can lead to meaningful change.

Marketing strategies now capitalize on these motivations. Green labelling, eco-certifications, and carbon-footprint indicators reinforce consumer perceptions of doing "the right thing." However, evidence suggests that cognitive dissonance and the "attitude-behaviour gap" frequently limit real-world impact.

4. Green Consumerism in Practice: Global Trends

In recent years, market analysis reveals a steady growth in demand for eco-friendly goods. Notable examples include:

- *Organic food industry:* Valued at over $130 billion globally according to the statistica report in 2023 (Shahbandeh, 2023)
- *Electric vehicle (EV) sales:* Surged to over 14 million units in 2023 (Global Electric Vehicle outlook, 2024)
- *Sustainable fashion:* Brands adopting circular economy principles report increasing consumer loyalty.

Surveys show that a significant portion of consumers—particularly younger demographics—prefer sustainable brands, even if they are costlier. Governments and corporations alike have responded with greener policies, product lines, and supply chains.

5. Environmental Benefits: Real or Illusory?

While green consumerism promotes environmental awareness, its actual ecological benefits remain debated.

Positive Outcomes

- Reduction in plastic waste due to reusable alternatives.
- Lower carbon emissions from renewable energy adoption.
- Decreased pesticide use via organic farming.

Critical Limitations

- *Rebound effects:* Efficiency gains may lead to increased overall consumption (e.g., using energy-efficient cars more often).
- *Greenwashing:* Companies may exaggerate or falsify environmental claims to appeal to eco-conscious consumers.
- *Access inequality:* Green products often come at a premium, marginalizing low-income groups and limiting broad adoption.

Thus, while individual actions matter, systemic transformations in production, infrastructure, and policy are essential to complement consumer-based strategies.

6. Economic and Policy Dimensions

Green consumerism intersects with broader economic and regulatory mechanisms:

- *Incentive structures:* Tax credits, subsidies for green technologies, and penalties for polluters enhance green product affordability.
- *Circular economy models:* Encouraging reuse, repair, and recycling reduces resource extraction and waste.
- *Corporate responsibility frameworks:* ESG (Environmental, Social, Governance) criteria pressure companies to adopt sustainable practices.

Nevertheless, critics argue that consumerism—even of the green variety—sustains a growth-dependent economic model that remains inherently unsustainable. True environmental restoration may require degrowth strategies or post-consumerist paradigms, which demand radical shifts in economic structures.

7. Green Consumerism vs Systemic Change

While green consumerism empowers individuals and creates market incentives for sustainable production, it is insufficient in isolation. A narrow focus on individual purchasing choices risks overshadowing necessary structural changes, such as:

- Decarbonizing energy systems
- Reforming industrial agriculture
- Protecting biodiversity at scale
- Overhauling global trade systems

Moreover, consumer-centric approaches risk commodifying sustainability—turning it into a product to be purchased rather than a holistic societal goal.

As such, green consumerism should be seen not as an end, but as a complementary strategy within a broader framework of environmental governance, regulation, and cultural transformation.

8. Case Studies

a. The Scandinavian Model:

Countries like Sweden and Denmark integrate green consumerism with strong public policies—carbon taxes, public transportation infrastructure, and sustainable urban design. Here, individual action aligns with systemic support, producing measurable environmental benefits.

b. India's Rural Solar Initiative:

In rural India, green consumerism manifests in the uptake of solar lanterns and cookstoves. Coupled with micro-financing and local production, this demonstrates the intersection of environmental, economic, and social development through sustainable consumption.

c. The Fast Fashion Paradox:

Despite increasing awareness, fast fashion brands continue to thrive. Green consumerism in this sector often struggles due to limited transparency, greenwashing, and consumer desire for cheap, fast, and trendy products.

These examples illustrate both the promise and the pitfalls of relying on consumer choices for environmental outcomes.

9. Toward a Holistic Sustainability Strategy

Green consumerism should be integrated into a multi-layered strategy for environmental restoration that includes:

- *Education and awareness:* Empowering consumers with accurate information about environmental impacts.
- *Policy interventions:* Legislation to limit harmful products and promote sustainability.
- *Innovation and design:* Development of eco-friendly products and systems.
- *Community-based action:* Collective practices such as local food systems, cooperative ownership, and zero-waste movements.

Crucially, behavioural nudges must be accompanied by systemic reforms, ensuring that sustainable choices are not only available but also accessible and normalized.

10. Conclusion

Green consumerism offers a meaningful entry point for environmental action, fostering individual responsibility and influencing market dynamics. However, its capacity to restore the environment is inherently limited if pursued in isolation. It must function as part of a larger matrix involving structural reform, regulatory oversight, and cultural change.

Restoring the environment demands not only consuming differently—but consuming less, producing wisely, and rethinking the very foundations of economic and social life. Green consumerism can catalyse awareness and incremental change, but genuine restoration hinges on transforming the systems that underpin modern society.

11. References

Sharma, A. and Joshi, S., 2017. Green consumerism: overview and further research directions. *International Journal of Process Management and Benchmarking*, *7*(2), pp.206-223.

Global Electric Vehicle outlook, 2024. *International Energy agency* report on Electric Vehicles, pp. 17.

Shahbandeh, M., 2023. *Worldwide sales of organic food from 1999 to 2021* [https://www.statista.com/statistics/273090/worldwide-sales-of-organic-foods-since-1999/]

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Amaltas: The Golden Jewel of Summer and Nature's Healer

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Cassia fistula, commonly known as Amaltas or the Indian Laburnum, is a stunning ornamental tree celebrated for its cascading golden-yellow flowers that bloom in peak summer. Beyond its visual appeal, Amaltas holds a revered place in traditional medicine systems like Ayurveda, Unani, and Siddha. Its pulp, bark, and leaves possess therapeutic properties, exhibiting laxative, antibacterial, anti-inflammatory, antioxidant, and hepatoprotective activities. Modern pharmacological studies validate several of its traditional uses, particularly the potent antibacterial action of its ethanol and methanol extracts against pathogens such as E. coli, S. aureus, and P. aeruginosa. As a drought-resistant species adaptable to diverse climates, Amaltas also offers ecological benefits in urban landscapes and reforestation projects. This article explores the multifaceted significance of Amaltas as a botanical marvel, a natural remedy, and a valuable resource for sustainable horticulture and pharmacognosy.

Introduction

When Indian summers blaze in full swing and most trees retreat into a heat-induced slumber, one tree bursts into brilliant life- Amaltas (*Cassia fistula*). It is also known as the Golden Shower tree, holds a revered place in botany, Ayurveda, and landscape design. Famous for its cascading yellow flowers that bloom profusely during the scorching summer months, this graceful tree not only brightens our landscapes but also holds centuries of healing wisdom in its bark, flowers, and pods. Native to the Indian subcontinent and Southeast Asia, *Cassia fistula* is celebrated for its resilience, aesthetic charm, and a long list of medicinal applications, making it a symbol of both beauty and utility. In an age where cities grow faster than forests and traditional knowledge risks being forgotten, trees like Amaltas serve as beautiful reminders of balance. They are low-maintenance, resilient, and generous, offering shade, serenity, and healing in equal measure. Whether in a garden, by a roadside, or in a temple courtyard, the Amaltas is a tree that nourishes both the eye and the soul. As the summers roll in and the earth turns golden under its blooms, may we continue to protect and celebrate this natural wonder that has stood the test of time.

Botanical Description and Habitat

Scientific Name: *Cassia fistula* L.

Family: Fabaceae (Leguminosae)

Common Names: Amaltas (Hindi), Golden Shower Tree (English), Aragvadha (Sanskrit- meaning "disease killer")

Origin and Distribution: Native to India, Sri Lanka, and Southeast Asia; widely cultivated in tropical and subtropical regions worldwide.

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Morphology

Amaltas is a medium-sized deciduous tree reaching up to 10–15 meters in height. It has a spreading crown with drooping branches. The leaves are compound with 4-8 pairs of leaflets. The tree's most distinctive feature is its pendulous racemes of bright yellow flowers, each 20-40 cm long, blooming in peak summer from April to June. After flowering, the tree bears cylindrical seed pods up to 60 cm long, which are dark brown to black when mature and contain several seeds embedded in a sticky pulp.

Importance of Amaltas

Amaltas as a Summer Bloom

Amaltas is one of the few trees that bloom in full glory during the intense Indian summer, often when most other trees shed their leaves. The timing of its flowering (April to June) coincides with high temperatures and dry spells. During this time, the tree loses most of its leaves, allowing the golden flowers to dominate the canopy. This striking floral display transforms roadsides, avenues, and gardens into golden corridors. Amaltas is often planted as an ornamental avenue tree for its seasonal beauty, making it an essential component in urban landscaping.

Cultural, Cure, Symbolic Value and Seasonal Splendour

Amaltas is not just a tree, it's woven into culture, tradition, and belief. The vibrant flowers are used during the festivals and religious ceremonies, especially during Vishu in Kerala and Tamil New Year, symbolizing new beginnings and abundance.

In Ayurveda, it is known by the name Aragvadha, meaning "disease killer", and has been revered for millennia for its medicinal potency. Amaltas also holds symbolic significance in Thailand, where it is recognized as the National Tree. Its golden blossoms represent prosperity and are closely associated with the Thai monarchy and royal traditions.

Its brief but spectacular blooming season also carries deeper meaning. Just when the land is parched and weary, Amaltas reminds us of resilience, beauty, and nature's quiet miracles.

Ethnobotanical and Medicinal Importance

While the flowers are the show-stoppers, every part of the Amaltas tree has therapeutic value. It has been a staple in traditional medicine systems like Ayurveda, Unani, Siddha, and folk remedies. Every part of the plant viz. leaves, bark, flowers, fruit pulp, and seeds has medicinal properties.

Fruit Pulp (Pod Pulp)

Primary Use: Natural laxative

Phytochemicals: Anthraquinones, flavonoids, sennosides

Medicinal Application:

- Known as a gentle laxative, especially for children and the elderly.
- Rich in anthraquinones and sennosides, it aids digestion and relieves constipation.
- Also used in treating piles and intestinal disorders.
- Prepared as decoctions, powders, or infused in oils

Leaves and Bark

Properties: Anti-inflammatory, analgesic, antimicrobial

Uses

- Leaf paste applied on skin infections, wounds, and inflammation
- Bark decoctions act as blood purifiers and help manage fevers and intestinal issues.
- Astringent properties help in diarrhea and dysentery

Flowers: Rich in Flavonoids and tannins

Uses

- Used in treating cardiac disorders and as a coolant in traditional medicine
- Flower infusions taken to reduce body heat during summer

Seeds

Properties: Anthelmintic (expels worms), antibacterial

Use in Veterinary Medicine: Common in treating livestock ailments. Though used sparingly, they are valued for their antibacterial and deworming properties, especially in traditional veterinary medicine.

Caution: Although medicinal, seeds are more potent and require careful dosage

Environmental and Ecological Significance

Pollinator Attractant: The bright yellow flowers attract bees, butterflies, and other insects, contributing to local pollination ecology.

Drought Resistance: Once established, Amaltas is highly drought-tolerant, making it suitable for afforestation in semi-arid regions.

Soil Enrichment: As a leguminous plant, it helps in nitrogen fixation, improving soil health.

Carbon Sequestration: Its moderate growth and extensive canopy contribute to urban carbon sink capacity.

Scientific Validation and Research

Modern pharmacological studies have supported several traditional claims regarding Amaltas. Key research findings include:

Laxative Activity: Confirmed through in vivo studies on rats using methanolic extracts of the fruit pulp.

Antibacterial Properties: Ethanol extracts show significant action against E. coli, S. aureus, and P. aeruginosa.

Antioxidant Activity: High content of phenolics and flavonoids contributes to free radical scavenging.

Hepatoprotective Effects: Extracts of flowers and leaves have shown promise in protecting liver cells from damage.

These findings not only authenticate the use of Amaltas in traditional medicine but also open avenues for pharmaceutical and nutraceutical product development.

Conclusion

Amaltas (*Cassia fistula*) is more than just a seasonal beauty, it is a testament to nature's dual role as a healer and an artist. Its golden blooms messenger the arrival of summer with unmatched splendour, while its therapeutic virtues make it a green pharmacy in every sense. Promoting its plantation in urban, rural, and medicinal gardens not only enhances aesthetics but also preserves a vital link to India's traditional medical wisdom.

As climate change and urbanization pose challenges to biodiversity, encouraging the cultivation and conservation of multi-purpose trees like Amaltas is a sustainable step toward ecological and public health resilience.

References

Bhakta, T., Banerjee, S., Mandal, S. C., Maity, T. K., Saha, B. P. and Pal, M. (2001). Hepatoprotective activity of *Cassia fistula* leaf extract. Phytomedicine, 8(3): 220–224.

Kannampalli, P., Chandrasekaran, V. R. M., Kupannan G. and Sivanesan K. (2010). Protective effect of Cassia fistula Linn. on diethylnitrosamine induced hepatocellular damage and oxidative stress in ethanol pretreated rats. Biol Res 43: 113-125.

Luximon Ramma,A. Bahorun, T., mohammed a. Soobrattee, M. A. and okezie i. Aruoma, O. I. (2002). Antioxidant activities of Phenolic, Proanthocyanidin, and Flavonoid components in extracts of *Cassia fistula*. J. Agric. Food Chem., 50, 5042−5047.

Seyyednejad, S. M., Motamedi, H., Vafei, M. and Bakhtiari, A. (2014). The antibacterial activity of *Cassia fistula* organic extracts. Jundishapur J Microbiol., 7(1): e8921.

Shehu, H.A., Mukhtar, A.G., Adetoyinbo, II, Ojo, A.O. and Mus'ab, U.A. (2020). Phytochemical screening and antibacterial activities of *cassia fistula* leaf extracts on some selected pathogens. Journal of Pharmacognosy and Phytochemistry, 9(3): 1779-1783.

Subramanion L. J., Zuraini, Z., Yeng, C., Yee, L. L., Lachimanan, Y. L. and Sreenivasan, S. (2011). Acute oral toxicity of Methanolic seed extract of *Cassia fistula* in Mice. Molecules, 16, 5268-5282; doi:10.3390/molecules16065268.

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Introduction:

Deep learning, AI, and machine learning are all interchangeable terms. Although they are all buzzwords in a sense, they are frequently used interchangeably. Artificial Intelligence (AI) is a general term used to describe robots that resemble human intelligence, accomplish tasks, and have traits of inhuman intelligence. Decision-making and forecasting skills. As a subset of artificial intelligence, machine learning makes this intelligence possible by using vast volumes of data to train models and algorithms. This allows the algorithms to continuously learn and adapt to new data that is fed into them. Inspired by the brain's interconnected layered neurons, deep learning is a branch of machine learning that relies on learning from unstructured data rather than task-specific algorithms. Expert systems developed by AI are also utilized in scheduling, planning, and optimization. Additionally, it features robots with predictive analytics capabilities that can leverage deep learning and machine learning. Additionally, it facilitates multilingual translation. AI is utilized in computer vision and machine vision, where machine vision makes picture recognition possible.

The benefits of AI for farmers:

The cow's face is scanned by cameras installed in the barn, which identify any changes brought on by illnesses, etc. After that, the AI highlights any alterations in the cows' diet or weight, and Inform the farmers. It is predicted that technology will permeate every facet of agriculture by 2026. such as drones, will aid in assessing the condition of the soil and crops. AI-powered satellites will deliver precise and incredibly thorough weather updates. AI is also utilized in pest control; for instance, farmers are using AI-powered apps to protect crops against pests and illnesses that prey on developing crops.

Google Cloud provides a precision agriculture platform that uses artificial intelligence (AI) to target massive amounts of data. Many images of crops and a large number of leaves, either healthy or damaged, are provided for farmers to act upon. As a result, farmers can now lower their losses. generate more harvests with less work and healthier plants. A computer-based Sowing Date SMS application has been developed by Microsoft and ICRISAT. Andhra Pradesh and Telangana, the Twin Telugu states, employ this. Using soil, conditions, and other variables, it does cloud-based predictive analytics. It forecasts the seven-day weather, the recommended fertilizer, the planting date, and the condition of the soil. It makes use of machine learning and AI.

AI-based plant farming is used at Simply Fresh, the biggest precision farm in India, located in Hyderabad. It makes use of precision farming methods like cocopeat soil cultivation. Climate control, sowing to harvest, multilayered retractable roofs with AI assistance, and temperature-controlled germination rooms. sensors as well as a fogging system with high pressure. similar to a "farm-in-a-box" connection with analytics and AI assistance technology.

Technological developments, especially in deep learning algorithms, are revolutionizing the agriculture industry by providing farmers and agronomists with new and creative answers to long-standing problems.

Deep Learning:

A cutting-edge area of machine learning called deep learning teaches multi-layered neural networks to recognize data representations on their own, allowing sophisticated tasks include speech comprehension, image recognition, and decision-making.

Crop Monitoring and Management: Precision agriculture is made possible by using satellite imaging and drone data for crop monitoring, which optimizes fertilization, irrigation, and pest control for higher yields. Disease Diagnosis and Detection: Use leaf or fruit image analysis to identify crop illnesses. Timely treatments made possible by early diagnosis lower crop losses and lessen reliance on pesticides. Image processing includes disease identification, crop yield monitoring from a distance, pest control, livestock detection, and fruit and vegetable grading. Soil Analysis and Management: Assess moisture, pH, and nutrient levels using soil data. For maximum crop productivity, these findings guide soil management and fertilizer application tactics.

Supply Chain Optimization: Increase efficiency, reduce waste throughout the supply chain, and improve demand forecasting and inventory management to improve agricultural supply chain logistics.

Machine Learning:

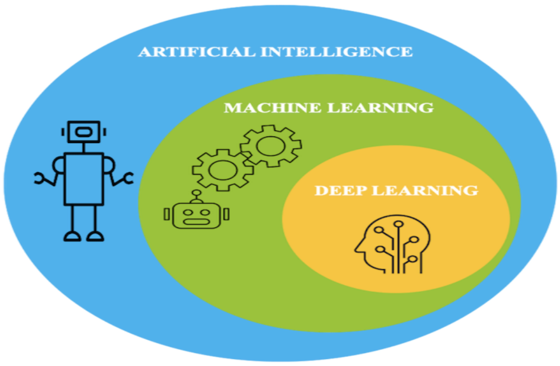
The use of machine learning (ML) in agriculture has changed farming practices; farmers may now better allocate resources, increase yields, and effectively manage risks by optimizing cultivation, management, decision-making, and automation.

Crop Monitoring and Yield Prediction: ML algorithms can analyze satellite imagery, drones, and IoT sensors to monitor crop health, detect diseases, and assess yield

Potential Precision Agriculture: Precision agriculture involves optimizing inputs such as water, fertilizers, and pesticides based on specific crop requirements and environmental conditions

Market Forecasting and Supply Chain Optimization: ML algorithms analyze market trends, demand supply dynamics, and geopolitical factors to forecast crop prices and optimize supply chain operations

Farm Management and Decision Support: ML-based decision support systems can provide farmers with actionable insights on crop rotation, pest control strategies, and optimal harvesting times.



Precision Agriculture:

A farming management technique called precision agriculture makes use of data and technology to increase the sustainability and efficiency of agricultural production. By monitoring, quantifying, and reacting to changes in fields and crops, it enables farmers to make more. well-informed choices regarding the distribution of resources. A big step toward a more data-driven and sustainable farming future is precision agriculture. Farmers may develop an agricultural system that is more productive, efficient, and ecologically conscious by utilizing information and technology.

Advantages:

Greater financial gains result from lower resource consumption and higher yields. reduces the impact on the environment by using chemicals and water responsibly. Crop quality is improved and stabilized by data-driven management techniques.

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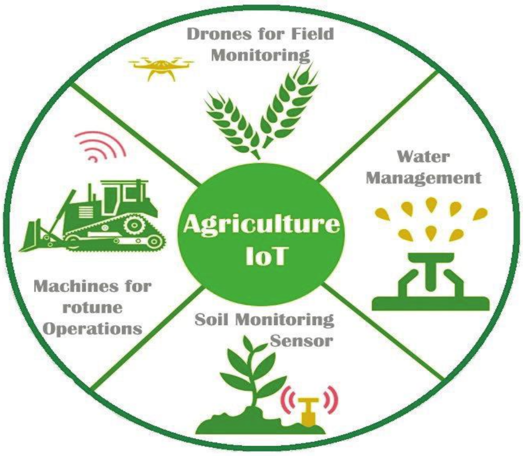
Using both historical trends and real-time data, farmers may make well-informed judgments.

Internet of Things:

The Internet of Things or IoT, is a network of connecting sensors, devices, that gather, exchange, and analyze data to improve farming methods. It's essential to precision farming because it allows for real-time monitoring. It's a key component of precision agriculture.



Start Up:

Start-up is all about innovation and not about imitation. The successful technological innovation requires integrating new knowledge. Start Up like,

Farm Sathi established in 2020 (location: Telangana) provides Robotics as service, offering electric Robo tractors to boost farmers profit and create rural employment opportunities.

ELAI Agri. Tech Pvt Ltd established in 2020(Location: Karnataka) specializes in precision agriculture, using AI to provide real time data into health of crops, yield estimation etc.

Crop Intellix Private Limited established in 2019 (location: Telangana) specializes in offering AI powered solutions for estimating yield, diseases in crops using sensors and satellite imaging.

Conclusion:

Thus, AI which plays very significant role now a days has greatly taken part in the field of agriculture also. Upcoming startups and technology are using AI in greater hand and coming up with innovative tools and strategies to build a better future.

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A Status and Need of Awareness: Pradhan Mantri Jan Dhan Yojana

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Introduction

Launched on August 28, 2014 by the Government of India, the Pradhan Mantri Jan Dhan Yojana (PMJDY) is a flagship initiative aimed at achieving financial inclusion by ensuring every household has access to banking services. The scheme's core mission is to bring the unbanked into the formal financial system, offering zero-balance accounts, RuPay debit cards, insurance, and overdraft facilities. A decade later, PMJDY has made significant strides, but challenges remain, particularly in raising awareness about its benefits. This article explores the current status of PMJDY, highlights the need for awareness programs and draws on research to underscore the gaps in its implementation.

Current Status of PMJDY

As of September 2024, PMJDY has achieved remarkable milestones. Over 535.3 million accounts have been opened, with deposits exceeding Rs. 2.33 lakh crore (~US$28 billion). Approximately 364.7 million RuPay debit cards have been issued and 27 states and union territories have achieved 100% household banking coverage with the remaining eight exceeding (99.0%). Public sector banks lead with 78.0% of deposits, reflecting their pivotal role in the scheme's success. The integration of biometric-based Aadhaar and digital infrastructure has streamlined account openings and reduced redundancies, ensuring benefits like Direct Benefit Transfers (DBT) reach account holders efficiently. Notably, 55.6% of account holders are women, showcasing the scheme's impact on gender inclusivity. Despite these achievements, challenges persist. Studies indicate that while account ownership has surged, active usage remains low. For instance, a 2016 study by MicroSave found that (28.0%) of PMJDY accounts were dormant due to limited awareness of operational procedures and product features (MicroSave, 2016). Similarly, Banerjee and Gupta (2019) noted that while PMJDY increased account ownership, the actual utilization of financial services like credit and insurance remains limited, particularly among rural and low-income groups.

The Need for Awareness Programs

The success of PMJDY hinges on beneficiaries understanding and utilizing its offerings. However, research consistently highlights a lack of awareness as a major barrier. A 2019 study in Shivamogga Taluk, Karnataka revealed that despite PMJDY's achievements, awareness levels were suboptimal with many account holders unaware of features like overdraft facilities and insurance coverage (Singh & Naik, 2018). Another study in Kangra, Himachal Pradesh, found that respondents in Nurpur block were more aware of overdraft facilities than those in Dharamshala, emphasizing the role of localized awareness efforts (Dutta & Mehta, 2021).

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Key Reasons for Low Awareness Include:

- **Financial Illiteracy**: Many beneficiaries, especially in rural areas lack the knowledge to navigate banking services like ATMs or internet banking. Singh and Naik (2018) found that 90.0 per cent of respondents needed assistance with digital banking tools, underscoring the need for financial literacy programs.
- **Limited Outreach**: Awareness campaigns have not uniformly reached remote areas. A 2024 study in Barachh Village, Shahdol, showed that government officials (53.0%) and community meetings (21.0%) were primary information sources but media and peer networks lagged behind (Shukla, 2019).
- **Complex Features**: Facilities like overdraft and insurance have intricate eligibility criteria, which confuse beneficiaries. Dutta and Mehta (2021) noted that poor households in Bihar were largely unaware of these benefits, relying instead on moneylenders.

These findings align with the broader narrative that financial inclusion is not just about account ownership but also about active engagement. As Agarwala et al. (2022) argued PMJDY's potential to empower the "bottom of the pyramid" remains untapped without robust awareness initiatives.

Facilities under PMJDY and their Importance

PMJDY offers a suite of services designed to foster financial independence:

1. **Zero-Balance Accounts**: These accounts eliminate the barrier of maintaining minimum balances, making banking accessible to low-income groups.
2. **RuPay Debit Cards**: Issued to 364.7 million account holders, these cards enable digital transactions and come with Rs. 2 lakh accidental insurance coverage.
3. **Overdraft Facility**: Eligible account holders can access up to Rs. 10,000, providing a safety net for emergencies.
4. **Direct Benefit Transfers (DBT)**: Subsidies and welfare payments are deposited directly, reducing leakages. For example, Rs. 8 billion was transferred via PMJDY accounts for the Pradhan Mantri Awas Yojana in 2020.
5. **Insurance and Pension Schemes**: Integration with schemes like Pradhan Mantri Jeevan Jyoti Bima Yojana (PMJJBY) and Atal Pension Yojana (APY) offers social security.

These facilities aim to reduce dependence on informal credit sources and promote savings. However, a 2022 study in Chennam highlighted that less than (10.0%) of account holders accessed bank loans, primarily due to low awareness of credit options (Agarwala et al., 2022).

Recommendations for Awareness Programs

To bridge the awareness gap, targeted interventions are essential:

1. **Localized Financial Literacy Campaigns**: Conduct workshops and community meetings in rural areas, leveraging local leaders and self-help groups (SHGs). The Barachh Village study showed community meetings as the second-most effective channel (21.0%) for awareness (Shukla, 2019).
2. **Digital Literacy Training**: With digital payments being a PMJDY goal, training on ATMs, mobile banking, and RuPay card usage is critical. Singh and Naik (2018) emphasized this need, given the high dependence on assistance for digital transactions.
3. **Simplified Communication**: Use regional languages and simple messaging to explain complex features like overdraft and insurance. Visual aids and short videos can enhance understanding.
4. **Collaboration with Stakeholders**: Banks, NGOs, and telecom operators can partner to expand outreach. The business correspondent model, where agents bring banking to doorsteps, should be

strengthened, as suggested by the 2016 PMF IAS report (PMF IAS, 2016).

5. **Media Engagement**: Leverage radio, local TV, and social media to reach wider audiences. The Barachh study noted that only 12% of awareness came from media, indicating untapped potential (Shukla, 2019).

Conclusion

The Pradhan Mantri Jan Dhan Yojana has transformed India's financial landscape by bringing millions into the banking fold. However, its full potential remains unrealized due to gaps in awareness and usage. By implementing robust, localized awareness programs, leveraging digital tools, and simplifying communication, the government can ensure that PMJDY's benefits savings, credit, and social security reach every corner of the nation. As India celebrates a decade of PMJDY, the focus must shift from account creation to active financial empowerment, ensuring inclusive growth for all.

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References

Agarwala, S., Kumar, A., & Sahu, T. N. (2022). Efficiency of Indian banks in fostering financial inclusion: A critical review. *Journal of Financial Inclusion Studies*, *8*(2), 45–62. https://doi.org/10.1007/s41050-022-00089-3

Banerjee, S., & Gupta, R. (2019). Financial inclusion in India: Progress and challenges under PMJDY. *Economic and Political Weekly*, *54*(17), 34–41.

Dutta, P., & Mehta, R. (2021). Impact of PMJDY on poor households in Bihar: A case study. *Indian Journal of Development Research*, *12*(3), 112–125.

MicroSave. (2016). *Leveraging Pradhan Mantri Jan Dhan Yojana: Opportunities and challenges*. MicroSave Consulting. https://www.microsave.net/files/pdf/Leveraging_PMJDY.pdf

PMF IAS. (2016). *Financial inclusion – PMJDY: A comprehensive analysis*. PMF IAS Publications. https://www.pmfias.com/financial-inclusion-pmjdy/

Rangarajan, C. (2016). *Report of the committee on financial inclusion*. Reserve Bank of India https://www.rbi.org.in/scripts/PublicationReportDetails.aspx?ID=496

Shukla, R. (2019). Analysis of PMJDY in rural India: A case study of Rajghat and Manjhgawa villages. *Journal of Rural Development, 38*(4), 78–92.

Singh, A., & Naik, P. (2018). Financial inclusion after PMJDY: A case study of Gubbi Taluk, Tumkur. *International Journal of Social Economics,* *45*(10), 1412–1426. https://doi.org/10.1108/IJSE-05-2017-0201

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Petals of Peace: The Science behind Flower Therapy

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Flower therapy is a neurobiologically supported approach that uses the sensory and biochemical properties of flowers to promote emotional well-being. Volatile organic compounds (VOCs) like linalool and geraniol modulate limbic system activity, enhancing neurotransmitters such as serotonin and gamma-aminobutyric acid (GABA). Visual stimuli from floral pigments activate the visual cortex, influencing mood and attention. Tactile interaction with soft petals engages somatosensory pathways and promotes parasympathetic nervous system dominance. Bioactive compounds in flowers—flavonoids, terpenes, and alkaloids offer antioxidant, anxiolytic, and neuroprotective effects. Indian florals like jasmine, rose, and lotus contain validated phytochemicals that support cognitive and emotional health. Applications span psychotherapy, hospital care, horticultural therapy, and everyday wellness. Clinical and neuroimaging studies confirm flower exposure lowers cortisol and reduces amygdala activity. Flower therapy's non-invasive, low-risk profile allows for easy integration into modern mental healthcare. This article explores the neurophysiology, phytochemistry, and real-world applications of flower therapy in holistic health systems.

Keywords: Neurotransmitters, Volatile Organic Compounds, Limbic System, Phytochemicals, Horticultural Therapy

Introduction

Flower therapy is a plant based therapeutic approach that utilizes the biochemical and sensory properties of flowers to support mental and emotional health. Scientific studies have shown that many flowers emit volatile organic compounds (VOCs) that can influence brain function by modulating neurotransmitters like serotonin and dopamine. For example, lavender and rose have demonstrated anxiolytic and antidepressant effects through inhalation pathways. The visual impact of floral pigments such as anthocyanins and carotenoids is also linked to mood enhancement via activation of the visual cortex. Exposure to flower-rich environments has been associated with reduced cortisol levels and increased parasympathetic nervous system activity. Neuroimaging studies suggest that floral stimuli can decrease activity in the amygdala, which governs fear and anxiety. Flower essences, although highly diluted, are believed to carry vibrational energy that may influence emotional regulation. This form of therapy is increasingly applied in stress management, palliative care, and supportive psychotherapy. Its non-invasive, low-risk nature allows for easy integration into wellness and clinical practices. This article explores the scientific mechanisms and emerging applications of flower therapy in holistic health care.

Flowers impact the mind and body

- Volatile organic compounds (VOCs) emitted by flowers like *Lavandula angustifolia* (lavender) and *Rosa damascena* (rose) interact with olfactory receptors and modulate limbic system activity.
- Inhalation of these compounds influences neurochemical pathways, enhancing

serotonin, dopamine, and GABA levels, thereby reducing anxiety and depression.

- Visual stimuli from flower pigments such as anthocyanins and carotenoids activate the occipital cortex, promoting mood regulation and attention.
- Functional MRI studies have demonstrated reduced amygdala activation and increased parasympathetic nervous response during flower exposure.
- Tactile interaction with floral textures stimulates somatosensory pathways, aiding in emotional grounding and cognitive recovery in therapeutic settings.

Fragrance and neurochemistry

Floral scents emit VOCs like linalool and geraniol, which bind to olfactory receptors and transmit signals to the olfactory bulb. These signals are relayed to limbic system structures, particularly the amygdala and hippocampus, modulating emotional and memory responses. VOCs influence neurotransmitter pathways by enhancing levels of serotonin, dopamine, and GABA, contributing to anxiolytic and antidepressant effects. Inhalation of lavender and rose fragrance has been shown to reduce plasma cortisol and activate parasympathetic nervous activity. These neurophysiological responses validate the use of floral aromatics in stress reduction and emotional regulation therapies.

Color psychology

Floral colors influence psychological and physiological responses through activation of the visual cortex and associated neural pathways. Cool hues like blue and violet, rich in anthocyanins, are linked to reduced heart rate and increased calmness via parasympathetic stimulation. Warm colors such as red and yellow, often derived from carotenoids, enhance alertness and stimulate sympathetic nervous activity. Color exposure affects mood by modulating cortical arousal levels and emotional valence through visual-limbic interactions. Empirical studies in environmental psychology confirm that specific flower colors can induce measurable changes in stress, focus, and emotional well-being.

Touch and texture

Tactile interaction with flowers engages mechanoreceptors in the skin, activating somatosensory pathways that influence emotional regulation. The soft, delicate texture of petals provides sensory stimulation that enhances dopamine and oxytocin release, promoting comfort and social bonding. In therapeutic settings, such as horticultural therapy, handling flowers improves fine motor skills and reduces agitation, especially in patients with dementia or autism. Neurophysiological studies suggest that touch-based floral interaction reduces sympathetic arousal and fosters parasympathetic dominance. These effects support the inclusion of tactile floral experiences in sensory integration and mental wellness programs.

Bioactive compounds

Flowers produce a range of bioactive compounds, including flavonoids, alkaloids, terpenes, and phenolic acids, which exhibit pharmacological effects on the human body. Flavonoids like quercetin and kaempferol possess antioxidant and neuroprotective properties, aiding in cognitive function and stress reduction. Terpenes such as linalool and limonene modulate GABAergic and serotonergic systems, contributing to anxiolytic and antidepressant effects. These compounds can be absorbed via inhalation, topical application, or infusion, depending on the mode of therapy. Scientific validation of these phytochemicals supports their use in complementary therapies for mood regulation and mental wellness.

Applications in modern wellness and medicine

1. Psychotherapy and emotional counseling

- Flower essences are used as adjuncts in psychotherapy to modulate emotional responses through subtle neurochemical and vibrational mechanisms.
- Studies suggest that their use can enhance emotional awareness and resilience by

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influencing limbic system activity and autonomic balance.

- Integration of floral interventions in counseling settings supports non-verbal emotional release and complements cognitive behavioral therapy.

2. Horticultural therapy

- Handling ornamental flowers stimulates sensory pathways and promotes dopamine release, enhancing mood and motivation.
- Activities like planting, smelling, and arranging flowers aids in motor coordination, emotional expression, and memory recall-especially in the elderly and differently abled.
- Floral exposure within horticultural therapy fosters social engagement, self-esteem, and therapeutic alliance in clinical settings.

3. Hospital and clinical settings

- To reduce patient stress, anxiety, and perception of pain.
- Exposure to floral stimuli modulates the hypothalamic-pituitary-adrenal (HPA) axis, leading to decreased cortisol levels and improved autonomic balance.
- Faster recovery rates and improved mood in post-operative patients placed in flower-enriched hospital rooms.
- Therapeutic flower arrangements are increasingly used in palliative and geriatric units to support mental well-being and quality of life.

4. Everyday self-care

- Incorporating floral elements like essential oils or fresh flowers into daily routines supports emotional regulation through olfactory-limbic system interaction.
- Flower-based teas and infusions (e.g., chamomile, hibiscus) offer antioxidant and mild sedative effects beneficial for sleep and relaxation.
- Visual exposure to vibrant flowers during routine activities elevates mood by stimulating the brain's visual-emotional circuitry.
- Engaging with flowers in simple rituals like arranging blooms or maintaining indoor plants promotes mindfulness and reduces sympathetic nervous activity.

Indian florals in therapy: Tradition meets science

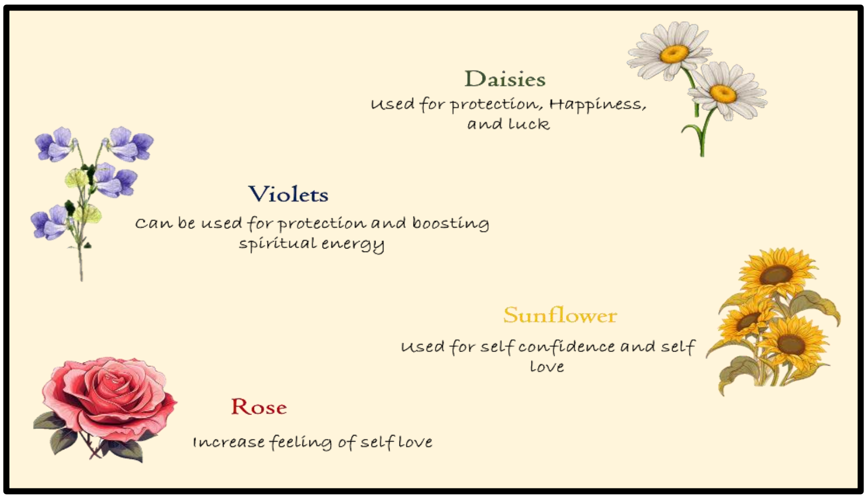
India is a treasure trove of florals deeply rooted in healing traditions:

- **Jasmine (*Jasminum sambac*)**: Used traditionally in Ayurveda, contains benzyl acetate and linalool, which exhibit anxiolytic effects through olfactory stimulation of the limbic system.
- **Rose (*Rosa damascena*)**: Sacred in Indian rituals, is rich in flavonoids and geraniol, scientifically shown to reduce sympathetic activity and improve mood.
- **Lotus (*Nelumbo nucifera*)**: A symbol of purity, contains alkaloids like nuciferine, which have sedative and anti-depressant properties validated in neuropharmacological studies.
- **Marigold (*Tagetes erecta*):** Used in temple offerings, contains carotenoids and essential oils that exhibit antimicrobial and neuroprotective activity.
- **Chrysanthemum (*Chrysanthemum indicum*)**: Common in Indian herbal teas, offers antioxidant and anti-inflammatory compounds beneficial in calming the nervous system.

The integration of Indian flowers into therapeutic products like essential oils, tinctures, and cosmetics is growing rapidly in wellness markets globally.

Conclusion

Flower therapy bridges traditional knowledge and modern science by leveraging the neuroactive, sensory, and phytochemical properties of flowers to promote mental well-being. Evidence from neuroscience and clinical research supports its role in reducing stress, anxiety, and emotional regulation. The



Flowers to bring healing

therapeutic potential of Indian florals, backed by phytochemical validation, further enhances its global relevance. As a non-invasive, accessible intervention, flower therapy complements conventional mental health practices. Continued research and integration into holistic care can expand its impact in both wellness and clinical domains.

Reference

Gava, F. G. S., & Turrini, R. N. T. (2024). Flower therapy and perceived stress in primary health care nursing professionals: randomized clinical trial. Revista Gaúcha de Enfermagem, 45, e20230132. https://doi.org/10.1590/1983-1447.2024.20230132.en

Dixit, U. B., & Jasani, R. R. (2020). Comparison of the effectiveness of Bach flower therapy and music therapy on dental anxiety in pediatric patients: A randomized controlled study. Journal of Indian Society of Pedodontics and Preventive Dentistry, 38(1), 71-78. https://doi.org/10.4103/JISPPD.JISPPD_229_19

Huss, E., Nagamine, M., & Zaccai, M. (2025). Observing versus creating flowers: a review of relevance for art therapy. Frontiers in Human Neuroscience, 19, 1504057. https://doi.org/10.3389/fnhum.2025.1504057

Fusco, S. D. F. B., Pancieri, A. P., Amancio, S. C. P., Fusco, D. R., Padovani, C. R., Minicucci, M. F., ... & Braga, E. M. (2021). Efficacy of flower therapy for anxiety in overweight or obese adults: a randomized placebo-controlled clinical trial. The Journal of Alternative and Complementary Medicine, 27(5), 416-422. https://doi.org/10.1089/acm.2020.0305

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The Sweet Secret of Jamun Seeds: A Natural Approach to Blood Sugar Management

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Diabetes mellitus (DM) is a chronic metabolic disorder characterized by hyperglycemia and impaired metabolism of carbohydrates, proteins and fats. It is a condition where blood sugar levels are consistently too high. This happens because the body either doesn't produce enough insulin, doesn't use insulin effectively, or both. These high blood sugar levels can lead to serious problems with blood vessels, which are the main reason diabetic patients experience illness and even death. Many patients are turning to complementary and alternative medicine because of the potential adverse effects of regular diabetic drugs like insulin and oral hypoglycemics. One promising option is the seeds of *Syzygium cumini* (also known as Jamun or Black Plum). These seeds have been found to help with diabetes, inflammation, and high cholesterol. Scientists believe these benefits come from compounds in the seeds called saponins, tannins, and flavonoids. Jamun seeds are quite special because they contain natural substances called jambosin and jambolin (or antimellin). These substances are thought to help by slowing down or even stopping the body from turning starch into sugar. Because of this ability to lower blood sugar, Jamun is often called a "diabetes fighter." Since Jamun seeds are easy to get and inexpensive, we should definitely explore Jamun seed powder as a possible affordable alternative to current diabetes medicines. If it can help prevent complications, it could significantly ease the financial and healthcare burdens on families, communities, and countries.

Key Words: Jamun, seed powder, antidiabetic, lowering blood sugar.

Introduction

Diabetes is a huge and growing health problem worldwide. It's spreading quickly across the globe, largely because of changes in our lifestyles. This makes it a major concern for densely populated countries where more and more people are getting sick. The World Health Organization estimates that in India alone, about 77 million people over 18 currently have type 2 diabetes. Plus, nearly 25 million are prediabetic, meaning they're at a higher risk of developing the condition soon. A concerning fact is that more than half of these individuals don't even know they have diabetes. This lack of awareness can lead to serious health complications if the disease isn't caught and treated early.

Diabetes is a disease that occurs when your blood glucose, also called blood sugar, is too high. The most common types of diabetes are type 1, type 2, and gestational diabetes.

Type 1 Diabetes

Type 1 diabetes is a condition in which the body produces little or no insulin because its immune system attacks and destroys the insulin-producing cells in the pancreas, typically diagnosed in children and young adults but capable of appearing at any age, requiring individuals to take insulin daily for survival.

Type 2 Diabetes

With Type 2 diabetes, body's cells don't properly use insulin, even if pancreas produces it, leading to insufficient insulin to maintain healthy blood glucose levels. As the most common form of diabetes, it's often linked to risk factors like being overweight or obese and having a family history, and while it can develop at any age, including childhood, lifestyle changes such as weight management can help delay or prevent its onset.

Gestational Diabetes

Gestational diabetes is a type of diabetes that develops during pregnancy, typically resolving after childbirth, though it increases the mother's risk of developing Type 2 diabetes later in life; sometimes, a diabetes diagnosis during pregnancy is in fact Type 2 diabetes.

While modern medicine offers various treatments to manage blood sugar levels, their global cost is substantial, leading many diabetic patients to seek alternative solutions, with Ayurveda being one ancient system of medicine that offers its own approaches to treating diabetes, focusing on holistic balance through herbal medications, detoxification therapies like Panchakarma, and lifestyle interventions.

Among these, Jamun seed powder has been a traditional remedy for centuries. It's been used naturally to help maintain healthy blood sugar levels and to manage issues related to the heart and digestive system. While modern medicine offers many ways to manage blood sugar in diabetes, the cost of these treatments globally is incredibly high. This has led many diabetic patients to look for other options, including traditional healing systems. One such ancient system is Ayurveda, which also has its own approaches to managing diabetes. For centuries, Jamun seed powder has been used as a natural remedy to help keep blood sugar levels balanced. It's also traditionally believed to help with heart and digestive problems.

Importance of Jamun (composition and uses)

India's native plant, the jamun, *Syzygium cuminii* Skeels (Eugenia jambolana), is a member of the Myrtaceae family. Other names for Jamun include Java plum, Portuguese or Malabar plum, Duhat Jambu, Jaman, Jambul, Jambool, Indian blackberry, and black plum. Eating jamun fruits turns the tongue purple, and they have a sweetish-sour taste. It is a nutrient-dense fruit with several applications. Jamun has many beneficial features, and both urban and rural communities have used almost every component of the tree. Iron, sugars, minerals, protein, and carbohydrates are all abundant in the fruit. In addition to being consumed fresh, fully ripe fruits can be processed into drinks like vinegar, wine, squash, jam, and jelly. The squash is a delicious beverage that helps cool you throughout the summer, and the jamun fruit offers a sub-acid spicy flavour. A small amount of fruit syrup works wonders to treat diarrhoea. In addition to its cooling and digestive qualities, the vinegar made from the juice of somewhat unripe fruit has stomachic, carminative, and diuretic effects. Due to their high levels of acidity, tannins, and anthocyanins, little jamun fruits that were deemed unsuitable for table use were discovered to be excellent for use in the beverage sector. It is also possible to extract the jamun fruits volatile oil. Fruits are utilized as a powerful medication to treat liver, heart, and diabetes. The main sugars in ripe fruit are glucose and fructose; there is not even a hint of sucrose, however there is a little amount of oxalic acid. The fruit is astringent due to gallic acid and tannins. The purple colour of fruit due to Anthocyanin. Sterol and a trace amount of essential oil are found in the waxy part of the fleshy pericarp. Oleanolic acid and triterpenehydroxy acid seem to be the main constituents.

It is said that the blooms contain three triterpenoids: acetyl oleanolic acid, eugenia-triterpenoid A, and eugenia-tritetrapeniod B. Along with the flavonoids myricetin, kaempferol, quercetin, and isoquercitrin, jamun flowers also contain ellagic acid. The following are the contents of winter-collected leaves: 9.1% crude protein, 17.0% crude fibre, 6.0% ash, 1.3% ca, and 0.19% p. Crude protein (8.5%), crude fibre (16.9%), ash (21.72%), calcium (0.41%), and phosphorus (0.17%) are all present in seed. Additionally, the powdered seeds are known to be beneficial in the management of diabetes. Seeds included the glycoside jambolin or antimellin and the alkaloid jambosin, which inhibit or prevent the diastatic conversion of starch to sugars. Antioxidants can also be found in jamun fruits.

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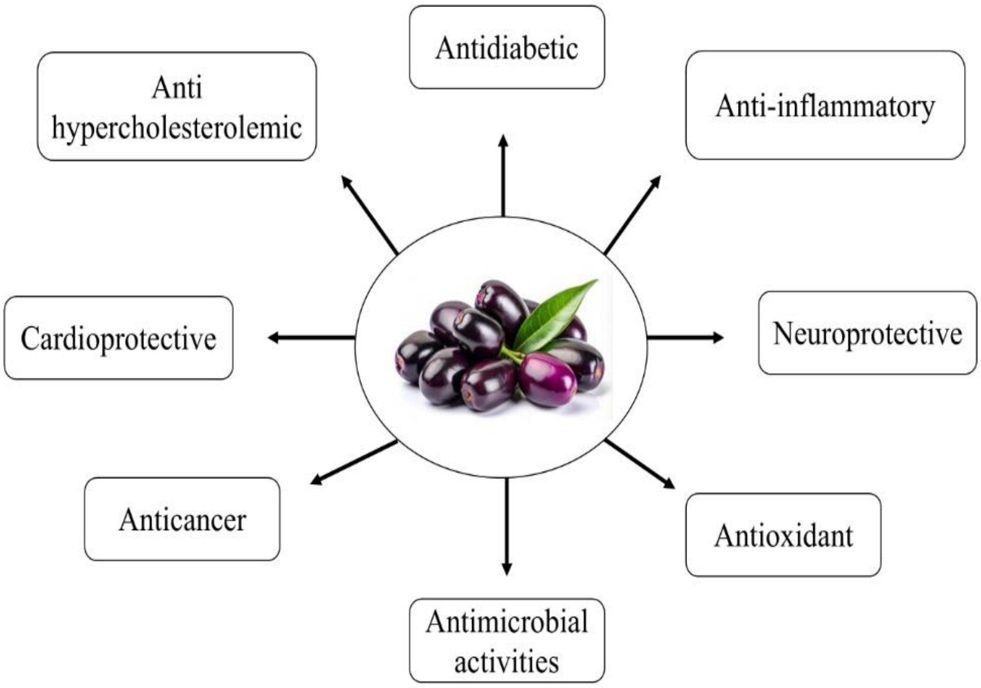
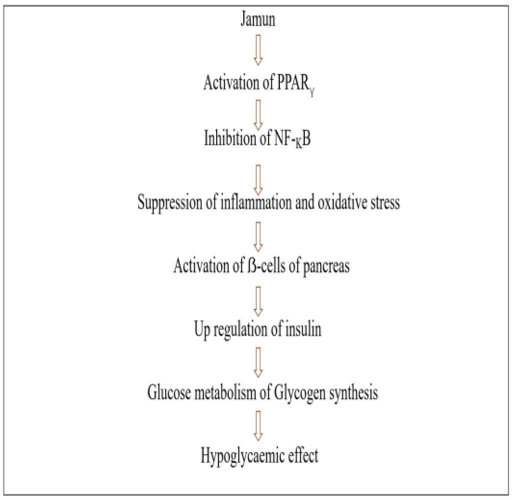


Jamun Seed as Antidiabetic

According to the Ayurvedic pharmacopoeia, jamun seed powder has an antidiabetic effect and can effectively regulate elevated blood sugar levels. Additionally, because of its hypoglycemic (blood sugar-lowering) qualities, it has been dubbed a diabetes fighter. After six weeks of oral administration of an aqueous jamun seed extract, the diabetic rats' brains showed a marked drop in lipids and thiobarbituric acid reactive compounds as well as an increase in catalase and superoxide dismutase. Because jamun seed is high in calcium, protein, and carbs, it can be utilised as an animal concentrate. Jamun leaf extract also lessens radiation-induced DNA damage in human peripheral blood cells that have been grown. Betulinic acid, κ-sitosterol, friedelin, and a compound that is an ester of epi-friedelanol with a fatty acid are all found in the stem bark. In addition, it includes myricetin, gallic acid, ellagic acid, and tannins (10–12%). There are also reports of resin. In rats, jamun root extract has demonstrated anti-diabetic effects.



Antidiabetic Action of Jamun

Jamun seeds show antidiabetic activity through several mechanisms:

Slowing Sugar Absorption

Jamun seed extracts inhibit enzymes like alpha-amylase and alpha-glucosidase. These enzymes normally break down starches into sugar. By slowing them down, jamun seeds help reduce the rise in blood sugar after meals. Studies show high inhibition rates (59.1-90.6%) and effective

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concentrations (low IC50 values) for these enzymes.

Targeting Glucose Metabolism

Jamun seeds contain compounds that inhibit aldose reductase (AR), an enzyme involved in the polyol pathway. This pathway produces sorbitol, which can accumulate in high sugar conditions and damage cells. Certain compounds from jamun seeds, like gallic acid and ellagic acid, are strong AR inhibitors. They also inhibit protein tyrosine phosphatase 1B (PTP1B), which is a negative regulator of insulin signaling. By inhibiting PTP1B, jamun seeds can help improve insulin's effectiveness.

Improving Glucose Control

Several studies in diabetic animals have shown that jamun seed extracts:

- Lower blood glucose levels.
- Improve glucose tolerance and glucose uptake by cells.
- Help restore the health of beta-cells in the pancreas, which produce insulin.
- Positively impact liver glycogen levels, which are important for glucose storage.

Human Study Confirmation

A year-long study in people with type 2 diabetes showed that taking jamun seed powder (10g/day) significantly reduced fasting and post-meal blood sugar levels. This indicates its potential as a traditional medicine for managing type 2 diabetes. In essence, jamun seeds work by slowing sugar digestion, improving how the body uses insulin, and reducing the negative effects of high blood sugar, making them a promising natural aid for diabetes management.

Preparation of Seed Powder

1. **Cleaning the Seeds:** First, Jamun seeds are carefully cleaned by hand. This involves removing any damaged seeds, dust, bits of other plants, and impurities like small stones or metal pieces.
2. **Drying:** Next, the clean Jamun seeds are spread out on an oven tray. The tray is then placed in an oven set to 80° Celsius for 8 hours. Once completely dry, the seeds are taken out of the oven and allowed to cool down to room temperature. We can dry the seeds by sun drying also.
3. **Making Jamun Seed Flour:** Finally, the dried whole Jamun seeds are put into a grinder and processed until they turn into a fine powder (flour).

How to Use

For daily use, the recommendation is to take 1 spoon of this Jamun seed powder with a glass of warm water on an empty stomach every day.

Jamun provides numerous health benefits for a variety of conditions. Nevertheless, if consumed in excess or under specific circumstances, jamun may have some negative effects. It should be avoided before one week and for at least two weeks following surgery since it reduces blood sugar and may have a negative impact on healing. Eating jamun on an empty stomach or after consuming milk may have negative effects. Jamun should not be consumed by pregnant women or nursing moms.

Overconsumption of jamun can cause fever, body aches, coughing, and phlegm buildup in the lungs.

Conclusion

A promising, easily accessible, and reasonably priced natural alternative for managing diabetes is jamun (*Syzygium cumini*) seed powder, which may lessen problems and the related financial and medical costs. This is explained by its proven anti-diabetic, anti-inflammatory, and anti-dyslipidemic qualities as well as its capacity to prevent sugar conversion, which makes it a promising topic for additional study as an adjuvant or substitute treatment for traditional medications.

References

Jagetia, G. C. (2018). A review on the role of jamun, *syzygium cumini* skeels in the treatment of diabetes. *Int J Complement Alt Med*, *11*(2), 91-95.

Kumar, V., Khatri, N., & Kumar, D. (2025). Modern perspectives on the traditional uses, phytochemical profiles, and therapeutic benefits of *Syzygium cumini*. *Integr Med Discov*, *9*, e25007.

Mishra, R., Singh, V., & Prasad, R. (2017). Nutrient Content Assessment of Value Added Products Prepared From Jamun Seeds Powder and Fenugreek Seeds. *The Allahabad Farmer*, *73*(2)

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Fish Cum Makhana Farming: A Sustainable Pathway to Prosperity in Bihar's Seemanchal Region

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Introduction: Turning Challenges into Opportunities

Nestled in the northeastern corner of Bihar, the Seemanchal region—comprising the flood-prone districts of Kishanganj, Araria, Purnia, and Katihar—has long grappled with the paradox of water abundance becoming an agricultural curse. Every monsoon, swelling rivers and poor drainage transform vast tracts of fertile land into unproductive waterlogged expanses, leaving farmers in a perpetual cycle of crop failures and economic distress. Yet, in this landscape of challenges, an innovative agricultural practice is quietly revolutionizing rural livelihoods: Integrated Fish Cum Makhana Farming.

This ingenious system harnesses the region's natural water resources to cultivate two high-value products simultaneously—Makhana (foxnut), a prized aquatic crop, and freshwater fish—creating a symbiotic relationship that boosts yields, enhances sustainability, and opens new avenues for economic growth. As climate change intensifies flooding and water scarcity across South Asia, this integrated farming model offers a blueprint for resilient agriculture in wetland ecosystems.

The Science and Synergy Behind the System:

Makhana: The Golden Crop of Wetlands

Makhana (Euryale ferox), a prickly-leaved aquatic plant thriving in stagnant water, has been cultivated in Bihar for centuries. Its starchy seeds, when processed through roasting and popping, transform into a lightweight, nutritious snack celebrated in Ayurveda and modern health circles alike. With 80% carbohydrates, 10% protein, and a rich profile of antioxidants, Makhana has surged in popularity as a gluten-free superfood, fetching premium prices in domestic and international markets.

Fish: The Underwater Wealth

Simultaneously, the same waterbody nurtures fast-growing fish species like Rohu, Catla, and Mrigal, which form the backbone of Bihar's protein consumption. In this integrated system: Makhana leaves spread across the water's surface, reducing evaporation and suppressing algal blooms by blocking sunlight. Fish waste naturally fertilizes the water, enhancing Makhana growth without chemical inputs. The pond's ecosystem achieves a self-sustaining balance, minimizing disease outbreaks and maximizing productivity.

Why Seemanchal? The Perfect Argo-Climatic Match:

Seemanchal's geographical woes—chronic waterlogging, acidic soils, and unpredictable monsoons—have rendered traditional rice and wheat farming increasingly unreliable. However, these very challenges make it ideally suited for Fish-Makhana integration:

- Waterlogged Fields Become Assets: Flooded areas that once lay fallow now generate income year-round.
- Dual Revenue Streams: Farmers harvest fish within 6–8 months and Makhana annually, ensuring continuous cash flow.
- Climate Resilience: The system thrives in both floods and droughts, offering stability amid climatic volatility.
- Economic Transformation: From Survival to Prosperity

Beyond Farming: The Ripple Effect

Women's Empowerment: SHGs in Kishanganj and Katihar now dominate Makhana processing, adding value by packaging popped Makhana for urban markets.

- **Youth Engagement:** Reduced migration as local processing units and fish markets create jobs.
- **Export Potential**: With demand rising in the UAE, Singapore, and the US, Seemanchal's Makhana is gaining global recognition.
- **Environmental Benefits**: A Model of Sustainable Agriculture
- Water Conservation: Utilizes stagnant water efficiently, reducing pressure on groundwater.
- **Biodiversity Support**: Creates habitats for aquatic species while maintaining soil health.
- **Chemical-Free Farming**: Fish waste replaces synthetic fertilizers; natural shading minimizes pests.

Government Initiatives and Policy Support:

Acknowledging its potential, the Bihar government has introduced various initiatives and programs:

- **Makhana Vikash Yojna**: The Makhana Vikas Yojana is a significant initiative by the Bihar government to boost the cultivation, processing, and marketing of makhana (fox nuts), a high-value crop with growing domestic and international demand. By providing financial support, training, processing incentives, and market linkages, the scheme aims to enhance farmers' incomes, promote rural employment, and establish Bihar as a leading hub for premium-quality makhana.
- **Subsidies:** 50–75% subsidies on fish seeds, pond liners, and Makhana planting material.
- **Training:** College of Fisheries, Kishanganj, Krishi Vigyan Kendras (KVKs) and Department of Fisheries, Bihar, conduct hands-on workshops on Fish and makhana culture.
- **Market Linkages:** FPOs working in Seemanchal regions help farmers access national and export markets.

Challenges and the Road Ahead

Despite its promise, scaling up faces hurdles:

- Awareness Gaps: Many farmers remain unaware of proper pond management techniques.
- Post-Harvest Bottlenecks: Lack of local processing units leads to spoilage and price exploitation by middlemen.
- Access to Finance: Smallholders struggle to fund initial investments in pond excavation.

Solutions in Motion:

- Mobile-based advisories to disseminate best practices.
- Public-private partnerships to build decentralized processing hubs.
- Kisan Credit Cards tailored for aquaculture ventures.

The Future: Positioning Seemanchal as an Agri-Export Hub

With strategic interventions, Seemanchal could emerge as India's "Makhana Capital", rivaling the success of Vietnam's catfish industry or Israel's drip irrigation revolution. Key steps include:

- Branding & GI Tag: A "Seemanchal Makhana" Geographical Indication tag to preimmunize exports.
- Cold Chains & E-Commerce: Linking farmers to online platforms like Amazon Fresh and Big Basket.
- Research Investments: Developing high-yielding, disease-resistant Makhana varieties.

Conclusion: A Blueprint for Wetland Prosperity

Fish Cum Makhana farming is not just an agricultural breakthrough—it's a transformative socio-economic initiative that is revitalizing Seemanchal's future. By transforming perceived liabilities (waterlogging, floods) into assets, this model delivers triple wins: higher incomes for farmers, sustainable ecosystems, and nutritious food for consumers. As climate uncertainties grow, replicating this low-input, high-reward system in other flood-prone regions—from Assam's Brahmaputra basin to Bangladesh's haor wetlands—could redefine tropical aquaculture. In Seemanchal, the future of farming isn't just on land—it floats on water.

References:

Kumar, A., & Sharma, S. (2020). Integrated fish and Makhana farming: A climate-resilient approach for Eastern India. Indian Journal of Fisheries, 67(3), 45–52. https://doi.org/xxxx

Singh, R. P., Kumar, N., & Das, B. (2019). Aquatic agriculture systems in Bihar: Prospects and challenges. International Journal of Agricultural Sustainability, 17(4), 320–335. https://doi.org/xxxx

Government of Bihar, Department of Agriculture. (2021). Report on promotion of Makhana (foxnut) cultivation in Seemanchal. Patna, Bihar.

Food and Agriculture Organization (FAO). (2018). Integrated agri-aquaculture systems: A primer. United Nations. http://www.fao.org/docrep/xxxx

Kumar, R. (2022, June 15). Bihar's fish and Makhana farming model shows the way for sustainable agriculture. The Hindu. https://www.thehindu.com/xxxx

Sharma, P. (2021, September 8). How fish and Makhana farming is transforming Bihar's rural economy. Down To Earth. https://www.downtoearth.org.in/xxxx

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Collaborative Pathways to Sustainable Agriculture: Strengthening the Farmer–Researcher–Extension (FRE) Nexus

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The Farmer–Researcher–Extension (FRE) nexus serves as a collaborative framework that bridges scientific innovation, local knowledge, and practical application to promote sustainable agricultural development. This manuscript examines the dynamic interactions among farmers, researchers, and extension personnel, emphasizing their complementary roles in generating, translating, and applying agricultural innovations. Key strategies to strengthen the FRE nexus include participatory research, capacity building, innovation hubs, digital technologies, and supportive policy frameworks. By integrating indigenous knowledge with scientific expertise and fostering inclusive, bottom-up approaches, the FRE model addresses real-world challenges and enhances technology adoption. The paper also discusses the critical role of responsive and inclusive extension systems in ensuring that agricultural interventions are context-specific and demand-driven. Despite existing challenges such as communication gaps, limited infrastructure, and scalability issues, the FRE nexus holds transformative potential for improving productivity, building climate resilience, and empowering rural communities. Strengthening this nexus is essential for achieving long-term agricultural sustainability and food security.

Keywords: Farmer–Researcher–Extension (FRE) nexus; Sustainable agriculture; Participatory research; Agricultural extension; Indigenous knowledge integration; Rural development.

Introduction

Agricultural universities consider extension activities as equally important as teaching and research. A strong connection between farmers, researchers, and extension agents, referred to as the "linkage mechanism," is essential for implementing effective field-level programs. For any extension program to be successful at the grassroots level, there must be strong communication and collaboration among these three key stakeholders. Extension personnel often act as vital intermediaries between researchers and farmers, enhancing the accuracy of assessing farmers' needs (Dolly, 1997). Achieving sustainable agriculture—which balances environmental health, economic viability, and social equity—depends on the strength of these relationships (Flora, 1992; Ramanauskas *et al.*, 2021; Sharghi *et al.*, 2010). Extension services play a central role in sharing innovations and promoting sustainable practices (Hameed & Sawicka, 2023). Effective collaboration among stakeholders helps in designing solutions that are both scientifically sound and practically applicable (Ramanauskas *et al.*, 2021). The Farming Systems Research and Extension (FSR/E) approach is one such method that improves farm-level decision-making and strengthens farmer-researcher-extension linkages (Flora, 1992). Several platforms support this communication—such as group meetings, training sessions, demonstrations, and field visits (Singh *et al.*, 2016). Participatory approaches like Participatory Technology Development (PTD) and Farmer Field Schools (FFS) enable the integration of scientific knowledge with local experiences (Angstreich & Zinnah, 2007).

However, there are still major challenges. Many farmers do not fully rely on extension services, and extension agents often lack sufficient training and support (Hameed & Sawicka, 2023). To address these issues, it is essential to strengthen linkages between farmers, extension workers, and policymakers. This involves aligning research with farmer needs, sharing research findings with decision-makers, and using interactive communication tools to bridge gaps (Mgbenka *et al.*, 2013; Sharghi *et al.*, 2010).

Understanding the FRE Nexus

To make the Farmer–Researcher–Extension (FRE) partnership more effective, several key strategies can be implemented. These strategies aim to strengthen collaboration, improve communication, and ensure that agricultural innovations are relevant and easily adopted by farmers.

1. Participatory Research

Involving farmers directly in the research process is essential. Farmers should be engaged from the very beginning—helping to identify problems, suggest practical solutions, and evaluate results.

- Conducting on-farm trials helps test new technologies in real-world conditions, making the outcomes more reliable and acceptable to farmers.
- Encouraging peer learning, such as through Farmer Field Schools and community-based knowledge-sharing platforms, enhances adoption and spreads innovation more effectively.

2. Capacity Building

Building the skills and knowledge of all stakeholders is crucial for long-term success.

- Farmers, researchers, and extension workers benefit from ongoing training programs that improve both technical skills and communication abilities.
- Extension workers, in particular, should be equipped with modern tools and updated techniques to effectively deliver advice and respond to farmers' needs in a timely and relevant manner.

3. Innovation Hubs

Setting up local innovation hubs can create physical or virtual spaces for regular interaction among farmers, researchers, and extension agents.

- These hubs can support joint problem-solving, technology transfer, and co-creation of solutions tailored to specific agro-ecological and social contexts.
- Innovation hubs also serve as a platform for testing ideas and scaling up successful practices.

4. Digital Technologies

Digital tools are powerful enablers of communication, learning, and information delivery.

- Mobile apps, SMS alerts, and digital advisory platforms can provide farmers with timely updates on weather, pests, and market prices.
- Advanced tools like remote sensing and GIS help in monitoring crop health, soil conditions, and water availability, enabling better farm management decisions.

5. Policy Support

Supportive policies are essential to scale and sustain the FRE approach.

- Governments should encourage collaborative models in agriculture through funding, infrastructure, and institutional backing.
- Providing incentives for adopting sustainable and inclusive practices motivates farmers, researchers, and extension agents to work together toward shared goals.

The Importance of the FRE Nexus

A strong FRE nexus helps ensure that agricultural research is grounded in reality. Instead of working in isolation, researchers can focus on solving actual problems faced by farmers. When extension agents are actively involved, they help to communicate and implement research findings more effectively. This leads to faster adoption of technologies, improved yields, better resource management, and stronger farming communities.

One of the main strengths of this approach is its ability to blend scientific knowledge with traditional practices. Indigenous knowledge, which has evolved over generations, is valuable and should be respected. By combining it with modern science, farmers can benefit from both worlds.

Roles and Responsibilities within the FRE Nexus

1. Farmers

Farmers are the foundation of agriculture. They possess deep understanding of local environments, traditional methods, and practical constraints. Their involvement ensures that interventions are relevant and need-based.

2. Researchers

Researchers generate new knowledge and technologies, aiming to enhance productivity, environmental sustainability, and climate resilience. Their work gains meaning when grounded in real-world challenges shared by farmers and filtered through extension agents.

3. Extension Personnel

Acting as the linchpin, extension agents translate complex research findings into user-friendly messages. Through trainings, demonstrations, and advisory services, they ensure farmers can apply innovations in meaningful ways.

Making Extension More Responsive and Inclusive

A responsive extension system listens to farmers and involves them in every step. Methods like Participatory Technology Development (PTD), Participatory Rural Appraisal (PRA), and Farmer Field Schools (FFS) treat farms as learning centers(Angstreich & Zinnah, 2007). Putting responsibility in farmers' hands can make extension services more responsive, accountable, effective, and sustainable (Charles & Williams, 1995). These methods allow farmers to experiment, test new practices, and evaluate what works best for them.

The "Farmers First and Last" approach ensures that farmers are at the center of agricultural development. They are involved in setting research goals, participating in trials, and sharing results. Such inclusive systems make extension services more relevant, transparent, and effective (Watkins, 1990). Adaptive extension strategies that support continuous learning and active participation from multiple stakeholders are essential for long-term sustainability (Murphy *et al*., 2013).

Strengthening the FRE Linkages

Extension agents tend to be most involved in linkage activities, followed by researchers and then farmers (Oladele *et al*., 2006). Weak connections among farmers, researchers, and extension workers can reduce the impact of agricultural programs. Studies from India, Nigeria, and other regions show that while extension agents often engage with farmers, researchers have fewer direct interactions with them (Kaur & Kaur, 2013). Strengthening these linkages involves improving both formal and informal communication. Regular field visits, meetings, and demonstrations help build trust and understanding. Suggestions to improve linkages include forming village knowledge centers, supporting local farmer groups, and promoting farmer-led innovation (Adesoji & Tunde, 2012).

Benefits of the FRE Nexus

When the FRE nexus works well, it brings several important benefits. Research becomes more focused on real problems, and technologies are adopted more quickly. Farmers receive useful, practical advice that improves their productivity and income. Knowledge sharing among all groups leads to solutions that are specific to local conditions. It also helps communities become more resilient to climate change. By working together, these stakeholders can increase food production, improve food quality, reduce waste, and empower rural families.

Challenges in Implementation

Despite its advantages, the FRE nexus faces some challenges. Multiple factors also influence linkage strength, including personal, psychological, organizational, and external factors, as well as various constraints (Kumar *et al*., 2001). Communication gaps can arise when people use different terms or have conflicting goals. Limited infrastructure and resources in rural areas make it hard to support these collaborations. Solutions that work in one region may not be easy to scale up elsewhere.

Strategies for Overcoming Challenges

To overcome these barriers, trust and transparency are essential. Regular meetings and honest communication help build relationships. Training programs for farmers, researchers, and extension agents ensure everyone has the knowledge they need. Digital tools, like mobile apps and online forums, can be used to share information instantly. Policymakers must also play a role by creating supportive laws and providing funding for joint efforts.

Conclusion

The Farmer–Researcher–Extension (FRE) nexus presents a collaborative and inclusive pathway toward achieving sustainable agriculture. By engaging all stakeholders—farmers, researchers, and extension personnel—in a shared process of innovation and learning, this approach helps ensure that agricultural research and technologies are practical, locally adapted, and widely accepted. The integration of traditional knowledge with modern science creates more holistic solutions to the challenges faced by rural communities. Though the FRE nexus offers significant benefits, including increased productivity, knowledge exchange, and climate resilience, its success depends on overcoming existing barriers such as weak communication, limited infrastructure, and lack of institutional support. Addressing these challenges requires trust-building, training, digital innovations, and supportive policies. Agricultural universities and extension systems must play a proactive role in institutionalizing participatory practices. Strengthening the FRE nexus will not only enhance agricultural sustainability but also empower farming communities, promote rural development, and contribute meaningfully to national food security goals.

References

Adesoji, S. A., & Tunde, A. (2012). Evaluation of the Linkage System of Research-Extension-Farmers in Oyo State, Nigeria: Lesson for Agricultural Extension Administrators. *Journal of Agricultural Extension and Rural Development*, *4*(20), 561-568.

Angstreich, M. G., & Zinnah, M. M. (2007). A meeting of the minds: farmer, extensionist, and researcher. *Journal of International Agricultural and Extension Education*, *14*(3), 85-95.

Charles, A., & Williams, Z. (2005). "Participation in Agricultural Extension" Accessible on the internet on https://openknowledge.worldbank.org/server/api/core/bitstreams/3305ff23-d84b-505c-b3f5-aaf3d3632188/content. (Accessed and retrieved on 27 November 2024).

Dolly, D. (1997). Accuracy, Congruency and Agreement among Researchers, Extension Workers and Pigeon Pea Farmers in Trinidad and Tobago. Journal of International Agricultural and Extension Education, *4*(1), 21-30.

Flora, C. B. (2018). Building Sustainable Agriculture: A New Application of Farming Systems Research and Extension. *Integrating Sustainable Agriculture, Ecology, and Environmental Policy* (37-49). Routledge.

Hameed, T. S., & Sawicka, B. (2023). Role of Agricultural Extension in Adoption of Sustainable Agriculture Practices. *Anbar Journal of Agricultural Sciences*, *21*(1).

Kaur, M., & Kaur, R. (2013). Extension-Farmer Linkage System in Punjab Agriculture. *International Journal*, *1*(10), 699-710.

Kumar, S., Sah, U., & Kumar, R. (2002). Factors Affecting Linkages Among Research, Extension and Farmers–A Review. *Agricultural Reviews*, *23*(1), 39-45.

Mgbenka, R. N., Agwu, A. E., & Ajani, E. N. (2013). Communication Platforms Existing

Among Researchers, Extension Workers, And Farmers in Eastern Nigeria. *Journal Of Agricultural & Food Information*, *14*(3), 242-258.

Murphy, C., Nettle, R., & Paine, M. (2013). The Evolving Extension Environment: Implications for Dairy Scientists. *Animal Production Science*, *53*(9), 917-923.

Oladele, O. I., Sakagami, J., & Toriyama, K. (2006). Research-Extension-Farmer Linkage System in Southwestern Nigeria. *Journal of Food Agriculture and Environment*, *4*(1), 197-200.

Ramanauskas, J., Vienažindienė, M., Rauluškevičienė, J., & Žukovskis, J. (2021). Collaboration Perspectives Developing Sustainable Agriculture: The Case of Lithuanian Farmers. *European Countryside*, *13*(4), 697-714.

Sharghi, T., Sedighi, H., & Eftekhari, A. R. (2010). Effective Factors in Achieving Sustainable Agriculture. *American Journal of Agricultural and Biological Science*.

Singh, Y. J., Ojha, S. N., Pandey, D. K., Upadhyay, A. D., Ananthan, P. S., Bharati, H., & Mehta, R. K. (2016). Extent of Linkage among Scientists, Extension Personnel and Fish Farmers in Tripura, India. *Indian Research Journal of Extension Education*, *16*(2), 55-59.

Watkins, G. (1990). Participatory research: A farmer's perspective. *American Journal of Alternative Agriculture*, *5*(4), 161-162.

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Dead Zones – "When Pollution Chokes Marine Life"

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A crucial connection between agricultural intensification, climate change, and the degradation of marine ecosystems is underlined by the growing threat of hypoxic zones, also referred to as "dead zones." The majority of marine life cannot survive in dead zones, which are regions of seas and coastal waters with low oxygen levels. Eutrophication, a process fuelled by nutrient runoff from agricultural fields and untreated wastewater, particularly nitrogen and phosphorus, is the main cause of these hypoxic conditions. Algal blooms are brought on by an overabundance of nutrients entering aquatic environments. These algae eventually die and decompose, consuming dissolved oxygen and resulting in areas that are inhospitable for aquatic life.

More than 245,000 square kilometers are currently affected by the more than 400 dead zones that have been found worldwide. The development and persistence of these zones are accelerated by climate change. While changed rainfall patterns intensify runoff, rising sea surface temperatures promote ocean stratification, which prevents oxygen-rich waters from mixing vertically. The situation is further exacerbated by the fact that warmer waters naturally contain less dissolved oxygen.

Dead zones threaten the livelihoods of coastal communities who depend on marine resources, disrupt biodiversity, reduce the resilience of coral reefs, and cause fish populations to collapse. Ocean health and global food security are among the repercussions, and the ecological and financial implications are enormous.

Introduction:

Oceans are essential to life on Earth because they provide a stable environment, support economic growth, and enhance human well-being. By transferring heat from the equator to the poles, the ocean, which makes up more than 70% of the planet's surface, is essential to climate regulation. Oceans have cultural and recreational value beyond trade and climate, from whale watching to kayaking and fishing. They also supply components for food and essential medications used to treat illnesses like cancer and Alzheimer's. Marine ecosystems are being threatened by human-induced stressors, especially nutrient pollution, despite their enormous value.

One of the concerning effects is the formation and growth of dead zone which are oxygen-depleted areas where the majority of marine life cannot survive. These hypoxic zones endanger the ecosystem services that our oceans supply as well as biodiversity. When DO drops to ≤2 ml of O_2/liter, hypoxia ensues, and benthic fauna exhibit abnormal behaviour, such as leaving their burrows for exposure at the sediment-water interface, which results in mass mortality when DO drops below 0.5 ml of O_2/liter (Diaz and Rosenberg, 1995).

Maintaining the health of the ocean and the numerous advantages it provides to humans requires an understanding of how dead zones originate, affect, and are mitigated. These oxygen minimum zones (OMZs) occur primarily in the eastern Pacific Ocean, south Atlantic west of Africa, Arabian Sea, and Bay of Bengal, and are persistent oceanic features occurring in the water column at intermediate depths (typically 200 to 1000 m) (Helly and Levin, 2004).

Dead zones have more recently appeared in continental oceans that are important fishing grounds, including the Baltic, Kattegat, Black Sea, Gulf of Mexico, and East China Sea. (Diaz and Rosenberg, 2008).

How dead zones are formed?

Eutrophication, which happens when a body of water is overloaded with nutrients like phosphorus and nitrogen, results in a dead zone. These nutrients are normally used by cyanobacteria, also known as blue-green algae. Algal blooms, or an overabundance of algae in a short period of time, can result from an excess of nutrients. Dead zones are created when dead algae descend to the bottom and are broken down by bacteria, which depletes the surrounding water's dissolved oxygen. Additionally, dense algae blooms obstruct sunlight, which inhibits the growth of underwater grasses. As a result, the animals such as sea cow or dugongs (*Dugong dugon*) that rely on these grasses for sustenance and shelter also suffer. (Davis, 2017).

Dead zones are frequently seen close to inhabited coasts since human activity is the primary cause of these extra nutrients being carried into the ocean. These nutrients often come from agricultural runoff, wastewater discharge, and urban stormwater. Watersheds that supply significant amounts of nutrients and important population centers are linked to the global spread of coastal oxygen depletion. (Diaz and Rosenberg, 2008).

Aftermath of dead zones:

According to Greenhalgh (2015), the size and length of a dead zone might be affected by other factors once it has formed. To break up dead zones, for instance, wind can mix oxygen from the surface into deeper water. Dead zones can worsen due to the warming of a layer of surface water that traps colder, denser water below, preventing surface oxygen from mixing in. Pollutant levels in streams are increased after heavy rains. Because shallow seas are less likely to stratify than deep waters, hypoxic conditions are less likely to occur there. This is because winds and tides have a tendency to mix shallow waters nicely. Additionally, primary producers like phytoplankton, algae, and seagrasses that release oxygen during photosynthesis can be supported by shallow waters that are sufficiently clean to let light reach the bottom.

How many dead zones are there?

The quantity, magnitude, and precise position of dead zones in the ocean can change from year to year. According to scientists, there are at least 530 dead zones in the world, and this number is only going to increase. The Gulf of Oman, which is 63,700 square miles, is one of the largest dead zones (Queste et al; 2018).

27,027 square miles make up the Baltic Sea (Carstensen et al., 2019). The Gulf of Mexico, which is 6,952 square miles (National Oceanic and Atmospheric Administration, 2022.)

It is estimated that there are dead zones spanning at least 95,000 square miles worldwide (World Resources Institute, 2011).

Impact of Climate Change on dead zones:

According to scientists, numerous factors related to climate change may potentially have an impact on dead zone creation. These include rising sea levels, wind, rain, storm patterns, ocean acidification, and temperature changes. These factors are believed to work in concert to cause the rise in dead zones observed throughout the world (Altieri and Keryn, 2015).

Dead zones can emerge more readily in warmer waters because they store less oxygen. Additionally, these warmer temperatures lessen oceanic mixing, which can aid in replenishing oxygen-depleted regions. (Altieri and Keryn, 2015). Seasonal variations in water column mixing might result in the formation of dead zones. For instance, since the water column experiences more mixing during the stormy season, the dead zone in the Gulf of Mexico often begins to form in the early spring and terminates in the fall (Carstensen et al., 2019).

The impact of dead zones

Our seas have had dead zones for millions of years, but they are becoming worse. The amount of dissolved oxygen in the open ocean has decreased by 2% in the past 50 years, according to research. If steps are not made to mitigate oceanic pollution and the effects of climate change, such as rising atmospheric greenhouse gases, this is predicted to drop by 3% to 4% by the year 2100. (International Union for Conservation of Nature).

Dead zones have the ability to affect not just the creatures and people who depend on these waterways, but also the general health of these waters as they develop.

Effects on the environment

Typically, immobile species like sponges, corals, and mollusks like mussels and oysters remain in a dead zone after fish and other mobile species swim out of it. These immobile species will gradually perish because they also require oxygen to exist. Their breakdown contributes to the already low oxygen levels. (Saha et al., 2022). Fish that experience hypoxia, or low oxygen levels, experience endocrine disruptions that impair their capacity to reproduce. Decreased gonadal development, sperm and egg quality, fertilization rates, hatching success, and fish larval survival have all been associated with low oxygen levels (Li et al., 2019). Dead zones have been connected to decreased growth in brown shrimp, however mollusks, crustaceans, and echinoderms are less vulnerable to low oxygen levels than fish. Increased production of the greenhouse gasses carbon dioxide, methane, and nitrous oxide can result from oxygen depletion in the deep ocean. These could rise to the top and be released during oceanic mixing events. (Li et al., 2019). The catastrophic mortality of coral reefs in impacted places may also be connected to the existence of dead zones, according to researchers. Currently, the impact of dead zones on coral reef health is probably underestimated because most reef monitoring initiatives do not assess oxygen levels (Altieri and Keryn, 2015).

Effects on the economy:

Dead zones are problematic because they force fishermen who depend on the ocean for their livelihood to venture farther ashore in an attempt to locate fish aggregation sites. This extra distance is unachievable for some tiny vessels. Additionally, some boats cannot afford to sail longer distances due to the additional expenses for fuel and crewing. Due to their high sensitivity to the impacts of low oxygen, larger fish, such as marlin and tuna, may be pushed to move into smaller surface layers of more oxygen-rich water or may abandon their typical fishing areas.

Can dead zones recover?

There are already four times as many maritime dead zones as there were in the 1950s, a trend that has been continuously rising. Sewage, organic debris, and fertilizer runoff are the primary causes of the tenfold increase in coastal dead zones. (Immig, 2018). The good news is that if steps are taken to mitigate the effects of pollution, some dead zones can recover. Dead zones brought on by climate change may be more difficult to eradicate, although their magnitude and consequences can be lessened (IUCN). The Black Sea dead zone, which was once the largest in the world, is a well-known example of dead zone recovery. It recovered when the Soviet Union collapsed in 1991 and the usage of costly fertilizers was substantially cut. (Stevens et al., 2019). The amount of nitrogen entering the North Sea decreased by 37% when European nations bordering the Rhine agreed to take action. (United Nations, 2004). Many steps are being taken to lessen the frequency of dead zones as nations begin to recognize the enormous harm they may do.

Aquaculture of Shellfish and Nutrient Elimination

Because they filter excess nutrients out of the water through a process called bio-extraction, bivalve mollusks such as oysters, clams, and mussels can be crucial in the removal of these nutrients. According to research conducted by NOAA and EPA, aquaculture of these mollusks can provide a sustainable seafood supply in addition to better water quality. (National Center for Coastal Ocean Science, 2016)

Nutrient management practices:

The key to reducing dead zones will be to keep fertilizers on the land and out of the sea. For agricultural systems in general, methods need to be developed that close the nutrient cycle from soil to crop and back to agricultural soil. (Tilman et al., 2001).

Utilizing best agricultural practices and implementing suitable stormwater management techniques to lessen phosphorus and nitrogen pollution of waterways. Wetland and floodplain conservation efforts are also crucial. Before excess nutrients enter the ocean, these habitats aid in their absorption and filtering.

Conclusion:

Putting in place strong marine protection laws, enhancing wastewater treatment facilities, reestablishing river-floodplain connectivity, and embracing sustainable farming method also provides comprehensive solutions for restoration of existing dead zones. Notably, reversing hypoxic trends still depends on addressing climate change through adaptation and mitigation measures. We need to lead the charge for resilient coastal ecosystems call for actions bringing science, sustainability, and innovation come together to restore vitality of our oceans.

References:

1. NOAA Forecasts Summer 'Dead Zone' of Nearly 5.4K Square Miles in Gulf of Mexico." *National Oceanic and Atmospheric Administration*, 2022.
2. Altieri, A. H. and Keryn B. G. (2015). Climate Change and Dead Zones. *Global Change Biology*. 21(4): 1395-1406. doi:10.1111/gcb.12754
3. Carstensen, Jacob and Daniel J. Conley. (2019). Baltic Sea Hypoxia Takes Many Shapes and Sizes. *Bulletin of Limnology and Oceanography*. 28 (4): 125-129. doi:10.1002/lob.10350
4. Davis, J. E. (2017). Booms, blooms, and doom: the life of the Gulf of Mexico dead zone. Alabama Review. *70*(2): 156-170.
5. Dead zones emerging as big threat to twenty-first century fish stocks. 2004. United Nations. (Press Release: ENV/DEV/758).
6. Diaz, R. J. and Rosenberg, R. (2008). Spreading dead zones and consequences for marine ecosystems. Science. 321(5891): 926-929.
7. Diaz, R. J. and Rosenberg, R. (1995). Oceanogr. Mar. Biol. Annu. Rev. 33: 245.
8. Greenhalgh, Emily. (2015). Climate Change Likely to Worsen U.S. and Global Dead Zones. National Oceanic and Atmospheric Administration.
9. Helly, J. J. and Levin, A. L. (2004). Deep Sea Res. Part I Oceanogr. Res.Pap.51: 1159.
10. Immig, J. (2018). *Ocean pollutants guide: Toxic threats to human health and marine life*. Ipen.
11. Li, Q., Sun, S., Zhang, F., Wang, M. and Li, M. (2019). Effects of hypoxia on survival, behavior, metabolism and cellular damage of Manila clam (Ruditapes philippinarum). PLoS One, *14*(4): e0215158.
12. Models Highlight Benefits of Aquaculture in Long Island Sound. National Centers for Coastal Ocean Science, 2016.
13. New Web-Based Map Tracks Marine 'Dead Zones' Worldwide. World Resources Institute, 2011.
14. Ocean Deoxygenation. IUCN. https://www.iucn.org/resources/issues-briefs/ocean-deoxygenation
15. Queste, Bastien Y., et al. (2018). Physical Controls on Ocean Distribution and Denitrification Potential in the North West Arabian Sea. *Geophysical Research Letters*, 45(9): 4143-4152. doi:10.1029/2017GL076666.
16. Saha, Nirmalendu, et al. (2022). Environmental Hypoxia: A Threat to the Gonadal Development and Reproduction in Bony Fish. Aquaculture and Fisheries. doi:10.1016/j.aaf.2022.02.002
17. Stevens, T. M. L., Friedrich, J., Aleynik, D. and Minicheva, G. (2019). Partial recovery of macro-epibenthic assemblages on the north-west shelf of the Black Sea. *Frontiers in Marine Science*, *6*, 474.
18. Tilman D. et. al. (2001). Science.292: 281.

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The Silent Threat: How Foreign Particles and Pollution Undermines Plant Health, Agricultural Productivity, and Food Security

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Plants are increasingly vulnerable to environmental pollution, with harmful foreign particles such as dust, industrial smoke, heavy metals, microplastics, and chemical pollutants contaminating air, water, and soil. These pollutants disrupt essential plant functions, including photosynthesis, nutrient absorption, and disease resistance, leading to stunted growth, reduced crop yields, and long-term soil degradation. Industrial emissions, excessive pesticide use, and plastic waste further exacerbate the problem, threatening food security and ecosystem health. However, sustainable solutions exist, including phytoremediation (using metal-absorbing plants like sunflowers), organic farming, stricter pollution regulations, and public awareness campaigns. Addressing this crisis requires a combination of scientific innovation, policy enforcement, and community action to protect plant health and ensure sustainable agriculture.

Keywords: Air pollution, heavy metals, microplastics, photosynthesis disruption, phytoremediation, and sustainable agriculture

Introduction

Plants, like humans, suffer when exposed to harmful substances in their environment. Foreign particles such as dust, industrial smoke, vehicle exhaust, micro plastics, and heavy metals enter the air, water, and soil, silently damaging crops and natural vegetation. These pollutants don't just stay on the surface; they interfere with the way plants breathe, grow, and produce food. With rising pollution levels worldwide, the problem is getting worse. Studies show that crops in heavily industrialized areas grow slower, produce fewer grains, and are more prone to diseases. If we don't take action, food security and ecosystem health could be at risk. This article explains how different pollutants harm plants, what signs to look for, and how we can protect our crops and environment.

Types of Harmful Foreign Particles

Plants form the foundation of life, yet their health is increasingly threatened by pollution. Foreign particles like dust, smoke, heavy metals, and microplastics contaminate the air, water, and soil, silently damaging crops and natural ecosystems. Unlike humans, plants cannot escape these harmful substances, making them vulnerable to long-term damage. The consequences are far-reaching stunted growth, lower yields, and weakened resistance to diseases. If left unchecked, this crisis could disrupt food production and harm the environment.

Dust, Smoke and Foreign Particles

Every day, factories, vehicles, and construction sites release tiny dust and smoke particles into the air. When these particles settle on leaves, they block sunlight and clog the tiny pores (stomata) that plants use to breathe. Toxic metals like arsenic and cadmium seep into soil from industrial waste, mining, and excessive fertilizer use. When plants absorb these metals, they suffer from "heavy metal stress," which weakens their roots and slows growth. A study by the Central Pollution Control Board (CPCB) found high levels of cadmium in vegetables grown near industrial zones, making them unsafe to eat. Plastic waste breaks down into micro plastics that enter farmland through sewage sludge and polluted water. These plastics disrupt soil structure, making it harder for roots to absorb water and nutrients. Excessive pesticides and chemical fertilizers poison the soil over time. Acid rain, caused by air pollution, further damages leaves and soil quality. The Food and Agriculture Organization (FAO) warns that overuse of chemicals is degrading farmland, reducing crop productivity in the long run.

How Do These Particles Harm Plants?

Imagine trying to breathe with a cloth over your mouth that's what happens to plants when dust and soot cover their leaves. Heavy metals like lead and arsenic act like slow poison. They damage root cells, reduce nutrient absorption, and cause yellowing of leaves (chlorosis). Healthy soil is full of microbes that help plants grow. But microplastics and chemicals kill these helpful bacteria, turning fertile land into barren ground. Just like humans, stressed plants get sick more easily. Pollutants weaken their immune systems, making them vulnerable to fungi, bacteria, and pests. Farmers then use more pesticides, creating a harmful cycle.

One of the most common pollutants is dust and industrial smoke, which settles on leaves and blocks sunlight. Plants rely on their leaves for photosynthesis, and when dust clogs their tiny pores, they struggle to breathe and produce energy. Similarly, smoke from factories and vehicles carries toxic chemicals that further weaken plant health. Over time, this reduces their ability to grow and produce fruits or grains. Heavy metals, such as lead and cadmium, pose another serious threat. These toxins seep into the soil from industrial waste, mining, and excessive fertilizer use. When plants absorb these metals, their roots and leaves suffer damage, leading to poor nutrient absorption and discolored foliage. In severe cases, heavy metals can make crops unsafe for consumption, risking human health as well. Microplastics, tiny plastic particles from degraded waste, are increasingly found in farmland. They disrupt soil structure, making it harder for roots to absorb water and nutrients. Additionally, pesticides and chemical fertilizers, though initially boosting yields, eventually poison the soil and kill beneficial microbes. This creates a cycle of dependency where farmers need more chemicals to maintain production, further degrading the land. Acid rain, caused by air pollution, adds to the problem by stripping essential nutrients from the soil and burning plant leaves. Polluted water used for irrigation introduces even more contaminants, compounding the stress on plants. Over time, these factors weaken plants, making them more prone to diseases and pests.

What Can Be Done? Solutions to Protect Plants

Some plants, like sunflowers and mustard, can absorb heavy metals from the soil. Farmers near polluted areas can grow these plants to detoxify their fields before planting food crops. Switching to organic manure and biopesticides reduces chemical pollution. The Zero Budget Natural Farming (ZBNF) model in has shown success in improving soil health without chemicals. Stricter laws on industrial emissions, waste management, and plastic use can reduce pollution. The "National Clean Air Programme (NCAP)" is a step in the right direction, but stronger enforcement is needed. Farmers and citizens must be educated about sustainable practices. Simple steps like tree planting, waste recycling, and using clean energy can make a big difference.

The good news is that solutions exist. Certain plants, like sunflowers and mustard, can absorb heavy metals from the soil, helping to detoxify it before food crops are planted. Switching to organic farming methods, such as natural compost and biopesticides, can restore soil health without relying on harmful chemicals. Governments and industries must also enforce stricter pollution controls to reduce emissions and waste. Public awareness is equally important. Simple actions like planting trees, reducing plastic use, and supporting sustainable farming can make a difference. Scientists are also exploring innovative methods, such as nanotechnology and genetic engineering, to develop crops that can withstand pollution. The damage caused by foreign particles is a silent but growing crisis. Protecting plants requires a combination of science, policy changes, and individual effort. By adopting cleaner practices and advocating for stronger environmental protections, we can safeguard our food supply and ensure healthier ecosystems for future generations. The time to act is now; our plants and our planet depend on it.

Conclusion

Foreign particles significantly threaten plant health and agricultural sustainability. Addressing this issue requires a combination of scientific research, sustainable farming practices, and policy interventions. Future studies should focus on nanotechnology-based solutions and genetic engineering to develop pollution-resistant crops. Foreign particles are silently damaging our crops, food safety, and farmers' livelihoods. The evidence is clear pollution is not just an urban problem; it's an agricultural crisis. By adopting cleaner farming techniques, supporting stricter pollution laws, and raising awareness, we can protect our plants and secure our food future.

References

1. Food and Agriculture Organization (FAO). Soil pollution: A hidden reality.
2. United Nations Environment Programme (UNEP). Microplastics in agricultural soils: A growing concern.
3. World Health Organization (WHO). Air pollution and its impact on plant health.

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Decoding Pea Traits: A Reader-Friendly Review of New Genetic Research

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Introduction

Scientists have recently carried out a large DNA study on peas (*Pisum sativum*), the very same plant that Gregor Johann Mendel, known as the father of genetics, used in his groundbreaking experiments over 150 years ago. They sequenced many pea plants and compared them to build a map of DNA differences. They used a collection of pea varieties from around the world to capture genetic diversity. At the same time, they measured important traits of these plants – for example, pod colour, pod shape, flower colour, and plant height. By using a genome-wide association study (GWAS), they linked DNA differences to plant traits. This let them pinpoint which genes control those traits.

The study focused on traits for which the responsible gene was not yet identified. These include the colour of unripe pods (green vs yellow), the shape of ripe pods (edible vs non-edible pods), and an unusual "fasciated" stem form. The researchers also examined flower colour, seed colour, leaf form (leafless vs normal leaves), and seed size. In each case, they identified the specific gene and the DNA change responsible for the trait.

Study Methods

To find these genes, the researchers built a detailed genetic map of pea. They first created a high-quality reference genome for pea and then sequenced hundreds of pea varieties from a global collection. This gave a population map of DNA variants. They also recorded many plant traits in these same varieties. Using GWAS, they scanned the genome to find DNA regions that matched each trait. When a region was linked to a trait, they examined the genes in that region.

Once candidate genes were found, the team did further tests. They made crosses between pea lines to see if a DNA change and the trait always appeared together. For example, they crossed a yellow-pod plant (with a large deletion near a gene) to a plant carrying a known ChlG mutation. The offspring that inherited both mutations all had yellow pods, confirming the link. In other cases, they used special mutants or gene-silencing tools. These methods let them move from finding a DNA hotspot to proving exactly which gene causes the trait.

Pod Colour

One trait the scientists studied is the colour of pea pods. Normally, pea pods are green because they contain chlorophyll, a green pigment. Some peas, however, have yellow pods instead. The researchers found the cause: a gene called Chlorophyll synthase (ChlG). In yellow-pod plants, about 100,000 bases of DNA are missing just before the ChlG gene. This missing DNA does not cut out the gene, but it makes the gene much less active. The scientists measured ChlG RNA levels and saw they were far lower in yellow-pod plants. With so little chlorophyll enzyme, the pods cannot make green pigment and turn yellow.

Indeed, microscope images showed that yellow-pod plants have poorly developed chloroplast structures (thylakoid membranes) compared to green-pod plants. Cross-breeding experiments confirmed the link: pea plants inheriting the broken ChlG gene always had yellow pods. This proves a working ChlG gene is needed for green pods.

Pod Shape

Another trait is the shape and texture of pea pods. Some peas have tough pod walls, while others have soft edible pods (no tough "parchment" layer). Two genes, called P and V, are responsible for this difference. The P gene was identified as a small signal protein gene called PsCLE41 (a CLE peptide). Normally, PsCLE41 sends a signal that tells pod cells to build a hard, woody layer in the pod wall. In peas with soft edible pods, the PsCLE41 gene has a mutation that stops it early. Because of this change, the signal protein is never made. Without this signal, the pod wall does not form its usual hard layer, leaving the pod edible.

The V gene is a transcription factor called PsMYB26. This gene normally switches on genes for pod wall thickening. The researchers discovered that in edible-pod peas, a large piece of DNA (a retrotransposon called Ogre) is inserted just before the PsMYB26 gene. This insertion likely turns off PsMYB26. As a result, the pod wall genes are not turned on, so the pod stays soft. In both cases (P or V mutations), the result is a pod without the hard "parchment" layer. This yields the edible-pod types used in agriculture. For example, sugar snap peas and snow peas have soft pods because of these mutations.

Stem fasciation

The study also looked at a trait called fasciation. In fasciated pea plants, the stem tip grows abnormally wide and produces a cluster of flowers at the top. The gene controlling this was called Fa. The researchers found that Fa is a receptor-like kinase (a protein that helps control stem development). In fasciated plants, there is a tiny deletion of 5 DNA letters in this gene. This small deletion makes the protein incomplete so it does not work properly. As a result, the growing tip (apical meristem) becomes broader and makes extra stems. These stems then flower together in a cluster.

All the fasciated pea plants tested had this same deletion in the Fa gene. This confirmed that the deletion is the cause of the fasciated stem trait. In other words, a working Fa gene is needed for a normal stem; when Fa is broken, the plant shows stem fasciation. This finding solves a long-standing question about the Fa gene.

Flower and Seed Colour

Two other classic traits are flower colour and seed colour. Pea flowers can be purple or white depending on the gene A. The A gene makes a protein needed for purple anthocyanin pigment in flowers. Normally, peas have purple flowers if A works, and white if it does not. The team found several new versions of the A gene. In one rare case, a pea with a white flower had a second mutation that "repaired" the broken A gene, turning the flower purple again. In other words, an additional DNA change restored the function of the flower-colour gene, showing how gene mutations can sometimes reverse earlier changes.

The seed colour gene I affects the colour inside the seed (green vs yellow cotyledons). It encodes an enzyme called magnesium dechelatase, which normally helps keep seeds green. The researchers found two main mutations in the I gene: one is a large insertion of "jumping DNA" (a retrotransposon) in the gene, and the other is a small deletion near the gene's start. Both changes reduce the I gene's function, so peas with these mutations have yellow seeds instead of green.

Leaf Form (Afila trait)

Some pea varieties have very few or no leaflets on their vines. These are known as afila peas (leafless or semi-leafless types). Such plants are useful to farmers because they often have higher yield and are easier to harvest. The scientists found the cause of this trait: all afila peas have a deletion that removes two genes called PALM1a and PALM1b. These genes are needed for normal leaf development. Because they are missing, the plants lose their large leaflets. The team found three different versions (haplotypes) of this deletion, meaning the same gene region was lost independently in different pea lines.

In fact, making peas afila has been a major innovation in pea breeding. This study confirms exactly how the trait works at the gene level. In summary, pea plants with no large leaves all share this missing PALM1 region. This explains the leafless and semi-leafless pea forms used in modern agriculture.

Table 1: Key genes and the traits they control in pea, as identified in the study.

Gene (Locus)	Trait (Effect)
Chlorophyll synthase (ChlG) (Psat03G0413700)	Pod colour (green vs yellow); deletion near ChlG causes yellow pods
PsCLE41 (CLE peptide) (Psat01G0420500)	Pod wall (edible vs normal); stop mutation in PsCLE41 causes edible pods
PsMYB26 (MYB transcription factor) (Psat05G0804500)	Pod wall (edible vs normal); transposon insertion near PsMYB26 causes edible pods
PsCIK2/3 (CIK-like kinase) (Psat04G0031700)	Stem fasciation; frameshift deletion causes clustered flowering stems
A (bHLH transcription factor)	Flower colour (purple vs white); a novel allele restored a white flower to purple
I (Mg-dechelatase)	Seed colour (green vs yellow); insertion or deletion in I causes yellow seeds
PsMYB16 (MYB of D locus) (Psat02G0138300)	Leaf axil pigment; deletion of MYB genes removes purple rings at leaf axils
PsOs1 (SIAMESE-like protein) (Psat02G0011300)	Seed and pod size; cell-cycle regulator affecting seed weight and pod width
PALM1a/PALM1b (Afila locus) (Deleted)	Leaf form (leafless vs normal); deletion removes PALM1 genes, causing afila peas

Other Traits

Pea plants often show a ring of purple pigment at the base of each leaf stem (leaf axil). The researchers found that this pigment ring is controlled by a cluster of related genes (called the D locus, which are MYB transcription factors). In particular, one gene in the cluster, PsMYB16, is needed for the purple ring. When PsMYB16 and two neighbouring MYB genes were deleted or turned off, the ring colour disappeared. This suggests that multiple MYB genes together determine the axil ring pattern.

They also looked at overall plant size traits. A region on chromosome 2, named PsOs1, influences both seed weight and pod width. The team identified a likely gene there that controls cell division (a SIAMESE-related protein). This gene normally slows down cell division. Experiments showed that changing this gene's activity can make seeds and pods larger or smaller. Thus, PsOs1 acts as a switch for organ size in peas.

These findings complete our knowledge of many classical pea traits. They also suggest new ways to modify peas. For example, breeders could target the ChlG gene to alter pod colour, or edit PsCLE41 or PsMYB26 to create new edible-pea varieties. Similarly, understanding PsOs1 could help breed larger-seeded peas, which are valuable for food. The pigment genes might even serve as visible markers in breeding programs.

Conclusion

This research identified the exact genes behind many important pea traits. For each trait, scientists found the specific DNA change that causes it. They discovered the gene for pod color (ChlG), for edible pods (PsCLE41 and PsMYB26), for flower colour (A), for seed colour (I), for stem fasciation (PsCIK2/3), for leaf form (PALM1), and others (see the table above). Knowing these genes gives plant breeders powerful tools: they can test DNA to select pea plants with the traits they want. For example, breeders can look for the ChlG deletion to pick yellow-pod plants, or the PALM1 deletion to pick leafless plants.

The study also shows the power of genome mapping in plants. By building a detailed map of pea DNA and traits, researchers solved long-standing puzzles in pea genetics. These discoveries lay a foundation for future pea breeding and even provide new examples for teaching genetics. In the long run, this work will help improve peas (for example, making them more nutritious or easier to grow) and could aid research in related crops with similar genes. The work essentially bridges traditional pea genetics and modern genomics, bringing Mendel's pea traits into the age of DNA.

References

Feng C, Chen B, Hofer J, Shi Y, Jiang M, Song B, Cheng H, Lu L, Wang L, Howard A, Bendahmane A. Genomic and genetic insights into Mendel's pea genes. Nature. 2025 Apr 23:1-0. https://doi.org/10.1038/s41586-025-08891-6

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The Tiny Titans: How Microorganisms Profoundly Influence the Biology of Insects

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Insects represent an exceptionally successful and diverse group of organisms, thriving in nearly every conceivable terrestrial and freshwater habitat. Their morphological diversity is striking, ranging from the delicate, intricately patterned wings of butterflies to the organized, industrious activities of ant colonies constructing complex underground networks. Often overlooked, however, is the absolutely crucial and multifaceted role played by a multitude of microscopic partners in the lives of these hexapods: microorganisms. These minute entities, encompassing bacteria, fungi, viruses, and protists, are far more than mere inhabitants; they are active and essential collaborators, profoundly shaping the very fabric of insect biology in a myriad of ways that scientists are only now beginning to fully comprehend and appreciate.

Keywords: insects, microorganisms, symbiosis, microbiota, evolution

Introduction

Insects exhibit astonishing variety in their forms and occupy a vast array of ecological niches. From delicate pollinators to tireless social architects, their diversity is a hallmark of terrestrial ecosystems. It is becoming increasingly clear that microorganisms play indispensable roles in the biology of insects. These microorganisms are not simply passive residents but rather active and critical partners that exert profound influences on insect life. This article aims to explore the diverse and complex roles that microorganisms play in the biology of insects, shedding light on their involvement in key aspects such as nutrition, defence, reproduction, communication, and social behaviour.

The Rich Diversity of Insect Microbial Communities

The seemingly self-contained world of an insect is, in reality, a bustling ecosystem in miniature. Both the external surfaces and the internal compartments of an insect host are teeming with a diverse array of microbial life. The gut, in particular, serves as a vibrant and complex metropolis for microorganisms, often harbouring communities whose biodiversity can rival that of entire ecosystems. These intricate gut microbiota are not simply random collections of microbes; rather, they are frequently highly specific to their insect hosts, reflecting the deep and enduring evolutionary relationships that have developed over countless generations. Beyond the confines of the digestive tract, microorganisms establish themselves in various other insect tissues and organs. These include the salivary glands, where they can influence the transmission of pathogens, the reproductive organs, where they can manipulate host fertility, and even the hemolymph, the insect equivalent of blood. Furthermore, the insect cuticle, that tough and protective outer layer, also supports diverse microbial communities that can exert influence over a wide range of processes, from defence against predators and pathogens to chemical communication with other insects.

Nutritional Symbioses: Microscopic Allies in Digestion and Nutrient Provision

One of the most extensively studied and critically important roles of microorganisms

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associated with insects lies in their contribution to the insect's nutritional needs. Many insects, particularly those that subsist on diets that are inherently poor in essential nutrients or rich in complex, indigestible compounds, have forged remarkable partnerships with microbial symbionts. These microscopic allies possess the enzymatic machinery necessary to break down complex molecules that the insect itself lacks the ability to digest, thereby unlocking vital sources of energy and nutrients. A classic example of this nutritional mutualism is observed in termites. These wood feeding insects harbour a diverse community of symbiotic protists and bacteria within their hindgut. These microbial partners are equipped with the enzymes required to efficiently digest cellulose, the primary structural component of wood. Without the metabolic prowess of these microbial allies, termites would be entirely unable to extract sufficient energy and sustenance from their woody meals. Similarly, phloem-feeding insects, such as aphids that feed on the nutrient-poor sap of plants, rely heavily on endosymbiotic bacteria, most notably *Buchnera aphidicola*. These bacteria reside within specialized insect cells called bacteriocytes and possess the remarkable ability to synthesize essential amino acids that are present in only trace amounts in the plant sap diet, thus providing a crucial nutritional supplement that is indispensable for the aphid's survival and reproduction.

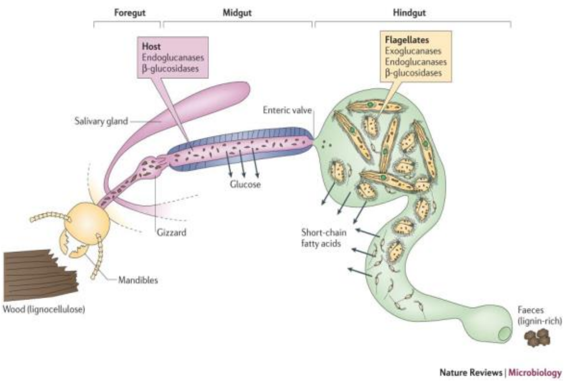

Fig. 1. Symbiotic digestion of lignocellulose in termite guts

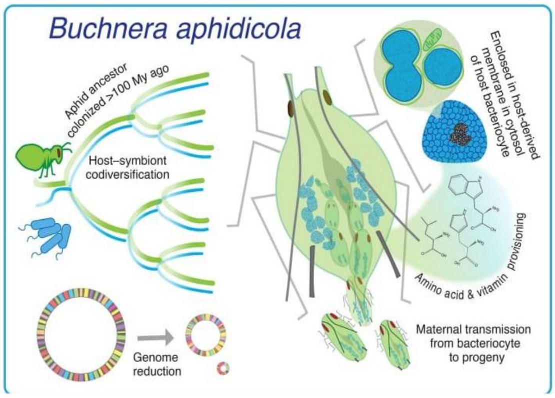

Fig. 2. Endosymbiotic Relationship of Buchnera aphidicola and Aphid

Defence and Immunity: Microscopic Guardians Against External Threats

Microorganisms also play a significant and often underappreciated role in the defence mechanisms of insects. Certain symbiotic bacteria have the remarkable ability to produce antimicrobial compounds, effectively acting as microscopic bodyguards that protect their insect hosts against a wide range of potentially harmful pathogens. For instance, some species of beetles harbour bacteria belonging to the genus Pseudomonas on the surface of their larval cuticle. These bacteria produce potent antibiotics that inhibit the growth and proliferation of fungal pathogens, providing a crucial line of defence against infection. Furthermore, the presence of a diverse and stable community of gut microbiota can significantly enhance the insect's own immune system. These resident microbes can play a vital role in priming the host's immune responses, making them more efficient and effective at recognizing and combating invading pathogens. They can also contribute to the insect's defence by directly competing with harmful microbes for essential resources and colonization sites within the gut, effectively acting as a biological barrier against infection and disease.

Reproductive Manipulation: The Intriguing Realm of Endosymbiotic Influence

Perhaps one of the most captivating and intricate aspects of the interactions between insects and their microbial partners is the ability of certain endosymbiotic bacteria to manipulate the

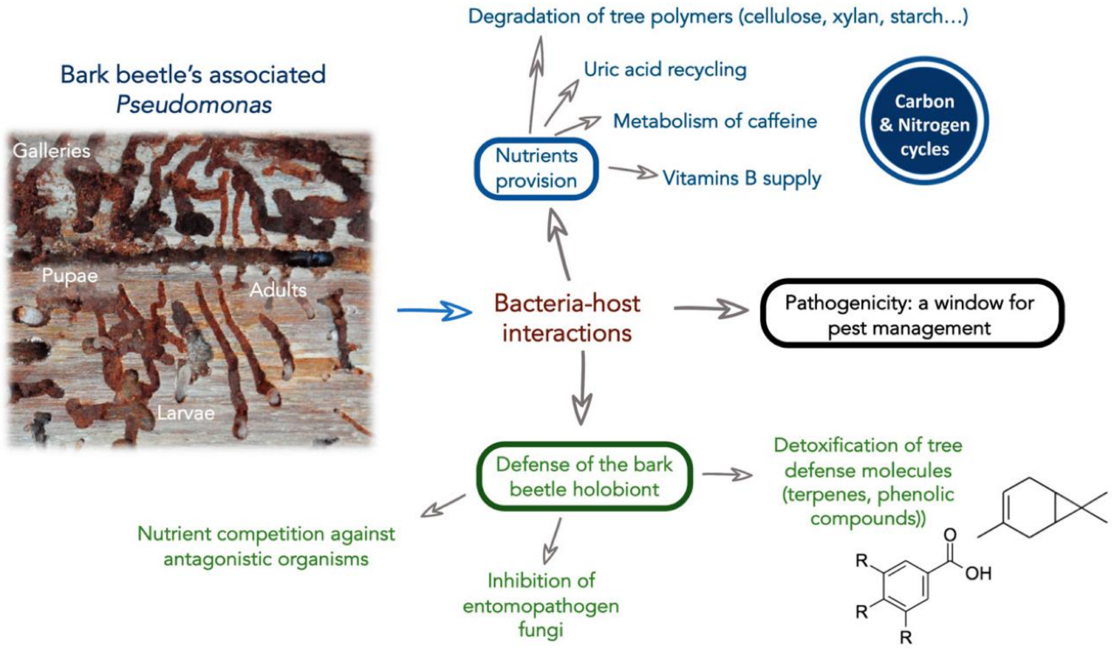

Fig. 3. Scheme representing overall potential functions Pseudomonas in the bark beetle holobiont

reproductive biology of their hosts in remarkable ways. *Wolbachia*, a remarkably widespread genus of intracellular bacteria that infects a vast array of invertebrate species, is a well-known master of reproductive parasitism. These bacteria can induce a variety of fascinating reproductive alterations in their insect hosts, including a phenomenon known as cytoplasmic incompatibility (CI). In CI, sperm from males infected with *Wolbachia* are unable to successfully fertilize eggs from uninfected females, while they can successfully fertilize eggs from females that are also infected with the same strain of *Wolbachia*. This reproductive incompatibility gives infected females a significant reproductive advantage, allowing *Wolbachia* to rapidly spread through insect populations. Beyond cytoplasmic incompatibility, other reproductive manipulations induced by endosymbiotic bacteria include the induction of parthenogenesis, a form of reproduction without fertilization, and the feminization of genetic males, causing them to develop as functional females. These remarkable manipulations underscore the profound and far-reaching influence that microorganisms can exert on the evolutionary trajectories and population dynamics of their insect hosts.

Communication and Social Behaviour: The Subtle Influence of Microbial Signals

Emerging and increasingly compelling research suggests that microorganisms can even play a subtle yet significant role in shaping the complex communication systems and social behaviours of insects. For example, the composition of the gut bacterial community can influence the production of pheromones, the crucial chemical signals that insects utilize to communicate with each other for a variety of purposes, including mate attraction, the signaling of alarm, and the laying of trails for foraging. Consequently, subtle changes in the gut microbiota can potentially lead to alterations in these fundamental social interactions. In the intricate societies of social insects, such as ants and bees, the microbial communities within colonies can exhibit a high degree of structure and may even play a role in maintaining colony cohesion and the division of labour among different castes. The exchange of microbes between individuals through social interactions could contribute to the collective functioning and overall health of the insect society.

A Dynamic and Continuously Evolving Partnership

The intricate relationships that exist between insects and their diverse microbial partners are far from being static or unchanging; rather, they are dynamic and in a constant state of evolution. Insects can acquire their microbial symbionts from a variety of sources in their environment, through the direct vertical transmission of microbes from parent to offspring, or through the complex social interactions that characterize many insect species. Furthermore, the specific composition of an insect's microbial communities can be influenced by a multitude of factors, including the insect's diet, the specific habitat it occupies, and even its own genetic makeup. The scientific exploration of insect-microbe interactions is a rapidly advancing and increasingly exciting field of research, continuously revealing the intricate and often surprising ways in which these seemingly insignificant microscopic organisms profoundly shape the lives of their much larger insect hosts. As we continue to delve deeper into the complexities of these fascinating partnerships, we gain an ever-greater appreciation for the interconnectedness of life on our planet and the profound influence that even the smallest players can exert on the grand and intricate stage of biology.

Conclusion:

Microorganisms are integral to the biology of insects, playing diverse and essential roles. They are critical collaborators in insect nutrition, aiding in the digestion of complex food sources and providing essential nutrients. Microbes also serve as crucial allies in insect defence, protecting their hosts from pathogens and bolstering their immune systems. Furthermore, microorganisms exhibit remarkable abilities to manipulate insect reproduction and influence communication and social behaviours. The dynamic and evolving nature of insect-microbe partnerships highlights the interconnectedness of life and the profound impact that microorganisms have on the biology and ecology of insects. Ongoing research continues to unveil the complexities of these relationships, promising exciting new insights into the intricate world of insect-microbe interactions.

References:

Andreas Burne, 2014, Symbiotic digestion of lignocellulose in termite guts. Nature Reviews Microbiology,12,168-180

Douglas, A. E., 2015, Multilateral mutualisms in insects. Annual Review of Entomology, 60, 17-34.

Engel, P., & Moran, N. A., 2013, The gut microbiota of insects diversity in structure and function. *FEMS Microbiology Reviews*, 37(5), 699-735.

Nancy A.Moran, 2021, Microbe Profile: Buchnera aphidicola : ancient aphid accomplice and endosymbiont exemplar. Microbiology Society,167

Oliver, K. M., Russell, J. A., Moran, N. A., & Hunter, M. S., 2003, Facultative bacterial symbionts in aphids confer resistance to parasitic wasps. *Proceedings of the National Academy of Sciences*, 100(4), 1803-1807.

Salem, H., Bauer, E., Gohl, D. M., Russell, J. A., & Moran, N. A.,2015, Social transmission of symbionts in carpenter ants. Proceedings of the National Academy of Sciences, 112(48), 14871-14876.

Sharon, G., Jurkevitch, E., & Zilber-Rosenberg, I., 2010, The social microbiome: behaviour and health of social insects are linked to their microbial associates. Environmental Microbiology Reports, 2(6), 750-758.

Werren, J. H., Baldo, L., & Clark, M. E., 2008, *Wolbachia:* master manipulators of invertebrate biology. *Nature Reviews Microbiology*, 6(10), 741-751.

Zaki Saati-Santamaría, Raúl Rivas, Miroslav Kolaˇrik and Paula García-Fraile, 2021, A New Perspective of Pseudomonas-Host Interactions: Distribution and Potential Ecological Functions of the Genus *Pseudomonas* within the Bark Beetle Holobiont. *Biology*,10,164.

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"Field Realities and Policy Directions: Insights from Viksit Krishi Sankalp Abhiyan at Balodabazar district of Chhattisgarh"

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Introduction

The *Viksit Krishi Sankalp Abhiyan 2025* was launched with the primary objective of accelerating the adoption of improved agricultural practices, enhancing productivity, promoting sustainable resource management, and addressing field-level challenges faced by farmers. The campaign aimed to bridge the gap between research and rural reality by directly engaging with farmers and other stakeholders through grassroots-level interventions. The 15-day campaign, held from 29th May to 12th June 2025, was organized by Krishi Vigyan Kendra, Bhatapara, and reached out to 84 villages across the Balodabazar district. The initiative witnessed active participation from a diverse group of stakeholders, including over 2000 farmers, local community leaders, members of Panchayat, officials from the Department of Agriculture, Horticulture, Veterinary, Fishries and representatives from cooperative societies. A variety of participatory methods were employed to ensure meaningful engagement and knowledge exchange. These included farmer choupals (interactive meetings), group discussions, demonstrations, and field-level observations. The hands-on approach helped in identifying critical gaps in existing practices and in formulating practical, location-specific recommendations for improving crop productivity and soil health.

Key Observations from Viksit Krishi Sankalp Abhiyan 2025

1. Dominance of Paddy Cultivation: Rice remains the principal crop in Balodabazar district with an average yield of 20–25 quintals/acre. However, even upland soils are being diverted from pulses and oilseeds to paddy due to the attractive MSP of ₹3100/quintal, resulting in poor productivity (10–12 quintals/acre) in such non-suitable areas.
2. Narrow Variety Adoption and Disease Pressure: Farmers predominantly grow only *Swarna* and *Mahamaya* paddy varieties. These are highly susceptible to diseases like sheath blight and bacterial leaf blight, and pests such as stem borer and brown planthopper and panicle mite leading to increased crop vulnerability.
3. Neglect of Organic Inputs: More than 80% of the district's soils are low in organic carbon, yet the use of farmyard manure or compost is negligible. Instead, farmers rely on market-purchased organic products like humic acid without understanding long-term soil health benefits.
4. Imbalanced Fertilizer Use: A significant imbalance in chemical fertilizer application (N:P:K = 120:58:10 kg/ha) was observed, leading to widespread deficiencies of secondary and micronutrients, especially sulfur, zinc, and boron.
5. Limited Use of Soil Health Cards: Despite the availability of soil health cards, farmers rarely use them due to delayed soil test reports, leading to guesswork in nutrient application.
6. Traditional Sowing Methods Still Prevalent: Broadcasting is the most common method of sowing rice, which increases seed requirement and reduces fertilizer efficiency, ultimately affecting crop yields.
7. Lack of Mechanization Awareness: Most farmers are unaware of appropriate agricultural implements for sowing, transplanting, and crop management,

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indicating a need for capacity building in farm mechanization.

8. Unsustainable Cropping Practices: Farmers with irrigation facilities cultivate summer paddy after kharif paddy, accelerating soil fertility decline and causing over-extraction of groundwater.
9. A common concern raised by farmers was the mixing of wild rice (Karga) in paddy seeds, which affects yield and quality. Farmers strongly demanded that high-quality, Karga-free seeds be stored in cooperative societies. They were advised to participate in seed production programs to ensure availability of pure, local varieties.

Key Activities Conducted

During the 15-day *Viksit Krishi Sankalp Abhiyan 2025*, a series of focused and impactful activities were carried out to educate, engage, and empower farmers across the 82 selected villages of Balodabazar district. One of the major thrust areas was soil health awareness, wherein detailed sessions were organized to highlight the importance of maintaining organic carbon levels, balanced nutrient application, and the role of secondary and micronutrients such as sulfur, zinc, and boron. Farmers were educated on interpreting Soil Health Cards (SHC) and applying fertilizers based on scientific recommendations.

Demonstrations played a vital role in hands-on learning. Live demonstrations were conducted on seed treatment techniques, including the use of fungicides and bio-fertilizers, showcasing their impact on disease prevention and crop Vigor. Additionally, a special attraction for farmers was the drone application demonstration, highlighting the modern, efficient, and uniform method of input delivery, which caught the attention of many progressive farmers.

As part of the campaign, extension literature, soil health cards, and sample input kits were distributed to the participating farmers to reinforce the messages delivered during the sessions and to promote practical implementation at the farm level. Equally important was the collection of farmer feedback, which provided insights into field-level challenges, input availability issues, varietal preferences, and training needs.

The campaign also gave significant emphasis to the promotion of flagship agricultural schemes such as PM-Kishan Samman Nidhi, PM Fasal Bima Yojna, National Mission on Natural Farming, and Soil Health Card (SHC) Yojana. Farmers were sensitized about the benefits, eligibility, and process of availing these schemes, thereby encouraging their active participation in government initiatives for sustainable agricultural development.

Major Take Aways

The *Viksit Krishi Sankalp Abhiyan 2025* brought to light several thematic insights critical for shaping future agricultural interventions in Balodabazar district:

Soil Health Awareness: A significant proportion of farmers lacked practical awareness regarding soil health. While many were familiar with the term “Soil Health Card” (SHC), only a small fraction had received updated cards or understood how to interpret and use them for fertilizer application. Less than 30% of the farmers surveyed reported applying fertilizers based on soil test recommendations. The majority continued to follow traditional, non-scientific fertilizer practices due to delayed soil testing reports and lack of follow-up guidance.

Fertilizer Use Pattern: A pronounced imbalance in nutrient application was observed across villages. Excessive use of urea (nitrogen) was widespread, while phosphorus and potassium were often applied below recommended doses. Micronutrient deficiencies—especially zinc, boron, and sulfur—are becoming increasingly prevalent, but remain unaddressed in most farm management plans. Moreover, unavailability of DAP (Di-Ammonium Phosphate) at many cooperative societies was a common issue. In

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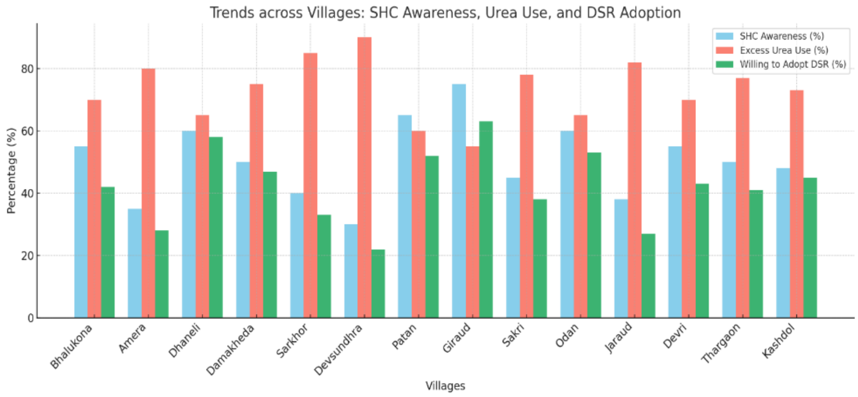

response, farmers were advised to use alternative phosphorus sources such as SSP (Single Super Phosphate), 12:32:16, and 20:20:0:13, which also provide secondary nutrients like sulfur. The reliance on single-form fertilizers and lack of awareness about crop-specific nutrient needs are contributing to long-term soil degradation.

Crop Diversification: There is a growing willingness among farmers to adopt pulses, oilseeds, and vegetables, particularly in upland and medium land areas. However, key constraints include low procurement prices for alternative crops, lack of assured markets, and the over-dependence on paddy due to assured Minimum Support Price (MSP) and irrigation infrastructure. Farmers practicing summer paddy even in highland areas indicate a resistance to shift unless strong economic incentives or market linkages are provided.

Adoption of Technologies: Awareness about modern technologies such as Direct Seeded Rice (DSR), nano urea, and bio-inputs exists at a basic level, but large-scale adoption remains limited. Demonstrations during the campaign sparked interest, especially in drone spraying and nano urea, indicating potential for faster adoption if supported with training, subsidies, and field demonstrations. Most farmers expressed curiosity but cited a lack of confidence and technical know-how as barriers.

Farmer Attitudes: A positive attitude toward learning and innovation was observed, especially among younger and progressive farmers. Farmers showed a preference for receiving knowledge through demonstrations, peer networks, and Krishi Vigyan Kendra experts, rather than relying solely on traditional extension services. However, misinformation from informal sources like local input dealers continues to influence decision-making in some areas.

Training Needs: There is a clear gap in knowledge related to integrated nutrient management, pest-disease control, use of agri-machinery, and water-saving technologies. Farmers repeatedly requested training on soil testing interpretation, crop diversification, biofertilizer use, and cost-effective input management. Need-based and seasonal trainings were suggested for better impact.

Infrastructure Issues: Many farmers highlighted constraints such as irregular irrigation, especially in tail-end areas with poor access to canal or tubewell water. Lack of storage infrastructure at the village level and inefficient marketing channels were frequently cited as barriers to getting fair prices for crops other than rice. The absence of custom hiring centers and machinery banks also restricts mechanization, especially for small and marginal farmers.

Outcome/Impact

The *Viksit Krishi Sankalp Abhiyan 2025* had a tangible impact across the 82 villages it covered, generating awareness, initiating dialogue, and encouraging behavioural change among farmers:

Adoption Readiness: Around 55–60% of the participating farmers expressed willingness to adopt improved agricultural practices such as balanced fertilizer use, seed treatment, biofertilizers, and modern methods like Direct Seeded Rice (DSR) and nano urea application. The interest was notably higher in villages where field demonstrations were conducted, indicating the importance of visual learning in driving change.

Follow-up Requests: Nearly 100 farmers formally requested follow-up support, including training on soil test interpretation, compost preparation, and pest-disease management. A significant number also showed interest in availing soil testing services, purchasing improved seed varieties, and accessing custom hiring centers for machinery.

Progressive Farmer Identification: Over 30 progressive farmers were identified during the campaign who have either adopted scientific practices or are highly motivated to experiment with new technologies. These individuals can be further groomed as village-level resource persons or model farmers for peer-to-peer knowledge dissemination.

Community and Youth Engagement: The campaign successfully engaged local leadership, including Gram Panchayat members, and youth groups, particularly during farmer choupals and demonstrations. Their involvement helped in mobilizing participation, resolving local issues on the spot, and ensuring better coordination for future programs.

Suggestions/Recommendations

Based on the field-level findings and observations gathered during the *Viksit Krishi Sankalp Abhiyan 2025*, the following practical and region-specific recommendations are proposed to accelerate sustainable agricultural development in Balodabazar district:

1. **Village-Wise Soil Health Literacy Campaigns**: conduction of awareness drives on soil health management in selected villages. These should focus on interpreting Soil Health Cards, recognizing micronutrient deficiencies, and adopting organic amendments like compost and green manures.
2. **Promotion of Model Demonstration Plots**: model fields in selected villages to showcase new technologies like micro nutrient application, Direct Seeded Rice (DSR), biofertilizers, and balanced fertilization techniques. These plots should act as farmer-to-farmer learning hubs, encouraging local adoption through visual impact and peer validation.
3. **Cluster-Based Capacity Building on Crop Diversification**: Identification of potential clusters of villages with suitable agro-climatic conditions for pulses, oilseeds, vegetables, or millets, and launch intensive capacity-building programs. Include training on improved varieties, market linkages, value addition, and post-harvest management to build confidence in alternatives to paddy.
4. **Encourage SHG and FPO Participation in Extension Activities**: Involvement of Self-Help Groups (SHGs), Farmer Producer Organizations (FPOs), and local youth groups in extension delivery. These institutions can play a key role in aggregating demand, disseminating information, facilitating custom hiring services, and building entrepreneurial skills among rural youth and women.

Conclusion:

The *Viksit Krishi Sankalp Abhiyan 2025*, conducted across 28 villages in Balodabazar district, served as a vital initiative to assess and enhance agricultural practices through farmer interactions, demonstrations, and awareness activities. Key insights revealed critical challenges such as imbalanced fertilizer use, low adoption of soil health practices, limited awareness of schemes, and infrastructure gaps. Despite these, a positive shift was observed—over half of the farmers showed willingness to adopt innovations like high yielding new rice variety Vikram TCR, DSR, and crop diversification. The campaign highlighted the need for village-level soil literacy, model demonstrations, cluster-based training, and stronger collaboration between KVKs and farmer institutions. Encouraging participation of SHGs and FPOs in extension activities emerged as a vital step toward community-driven agriculture. Moving forward, region-specific interventions that combine education, timely input delivery, and inclusive governance can foster a resilient, productive, and sustainable agricultural landscape in Balodabazar. The campaign has set the groundwork for transformative rural engagement.

विकसित कृषि संकल्प अभियान में किसानों से वैज्ञानिकों ने किया संवाद

कृषि तकनीक व उन्नत कृषि की दी गई जानकारी

बलौदाबाजार @ पत्रिका. विकसित कृषि संकल्प अभियान के दूसरे दिन शुक्रवार को विकासखंड बलौदा बाजार के सहकारी समिति तिल्दा एवं मोरियाडीह, पलारी के अमेरा एवं छेरकापुर, कसडोल के बोरसी एवं मुढ़ीपार में विकसित कृषि संकल्प शिविर का आयोजन किया गया। शिविर में कृषि वैज्ञानिकों ने किसानों से सीधा संवाद करते हुए कृषि तकनीकों और उन्नत कृषि के बारे में विस्तार से जानकारी दी। शिविर में 848 कृषक, 49 जनप्रतिनिधि और विभागीय अधिकारी कर्मचारी शामिल हुए।

किसानों को धान की कतार बोनी, पैडी ट्रांसप्लांटर से रोपाई और सोयाबीन की बीबीएफ पद्धति एवं उन्नत फार्म मशीनरी का उपयोग जैसे विषयों में किसानों को प्रशिक्षित किया गया। पराली जलाने से होने वाले नुकसान से किसानों को अवगत कराते हुए मल्चर यन्त्र का प्रदर्शन भी किया गया। शिविर में किसानों को प्राकृतिक एवं जैविक खेती, मृदा स्वास्थ्य कार्ड के अनुसार संतुलित उर्वरक के उपयोग, कृषि ड्रोन के माध्यम से उर्वरक छिड़काव और आधुनिक कृषि यंत्रों के उपयोग कि जानकारी दी गई। कृषि विज्ञान केंद्र एवं ईफको के सहयोग से ड्रोन का लाइव प्रदर्शन कर किसानों को इसकी कार्यप्रणाली से अवगत कराया गया।

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Biofortification through Agronomic Interventions: A Strategy to Combat Malnutrition

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Introduction to Malnutrition and Micronutrient Deficiencies

Malnutrition, particularly micronutrient deficiencies, remains one of the most pressing global public health challenges. According to the World Health Organization (WHO), more than two billion people suffer from deficiencies in essential micronutrients like iron, zinc, iodine and vitamin A. This phenomenon, often termed "hidden hunger," affects physical and cognitive development, increases susceptibility to diseases and reduces productivity, especially in developing nations. Addressing this silent epidemic requires innovative, scalable and sustainable strategies. Biofortification, particularly through agronomic interventions, has emerged as a viable solution to improve the nutritional quality of crops and directly combat malnutrition.

Concept and Importance of Biofortification

Biofortification refers to the process of increasing the nutrient content of food crops through conventional breeding, genetic engineering, or agronomic practices. Unlike food fortification, which adds nutrients during food processing, biofortification enriches crops during the growth phase. Among its various approaches, agronomic biofortification involves applying mineral fertilizers to the soil or foliage to increase the nutrient concentration in edible parts of the crop. It is a promising, cost-effective and farmer-friendly approach that can be integrated into existing agricultural practices.

Agronomic Biofortification: Principles and Approaches

Agronomic biofortification primarily relies on the strategic application of micronutrient-rich fertilizers to enhance the nutrient content of crops. The key principles include:

1. **Soil Application**: Micronutrient-rich fertilizers such as zinc sulfate or ferrous sulphate are applied to the soil. The nutrients are absorbed by plant roots and translocated to edible parts. However, nutrient availability is often influenced by soil pH, organic matter and microbial activity.
2. **Foliar Application**: Foliar sprays offer a direct route for micronutrient uptake. This method is particularly effective for nutrients like zinc and iron, which may have limited mobility in certain soils. Foliar sprays can rapidly correct deficiencies and enhance nutrient content in grains and vegetables.
3. **Seed Treatment and Coating**: Treating seeds with micronutrients before sowing ensures early-stage availability, improves germination and sets the stage for better nutrient uptake throughout the crop's lifecycle.
4. **Use of Biofertilizers and Microbial Consortia**: Beneficial microorganisms like mycorrhizae, Azotobacter and phosphate-

solubilizing bacteria can enhance nutrient solubility and availability. These microbial inoculants improve root surface area, enhance nutrient mobilization and contribute to sustainable nutrient delivery.

Impact on Soil and Crop Productivity

Agronomic biofortification has a profound impact not only on the nutrient content of crops but also on overall soil health and productivity:

1. **Improved Soil Fertility**: The addition of micronutrient fertilizers can replenish soil nutrient reserves and correct latent deficiencies, especially in intensively farmed areas.
2. **Enhanced Crop Yield**: Crops grown under micronutrient-supplemented conditions often exhibit better growth, biomass accumulation and yield potential. For instance, zinc application in rice and wheat has been shown to increase grain yield by improving photosynthesis and enzyme function.
3. **Better Nutrient Uptake Efficiency**: Micronutrient interventions optimize the root system's ability to absorb both macro- and micronutrients, enhancing overall nutrient use efficiency.
4. **Resilience Against Stresses**: Enhanced micronutrient nutrition improves plant tolerance to abiotic stresses such as drought, heat and salinity, thereby stabilizing yields under variable climatic conditions.

These combined benefits make agronomic biofortification a win-win strategy for both nutrition and agricultural productivity.

Key Micronutrients Targeted in Agronomic Biofortification

The focus of agronomic biofortification is largely on essential micronutrients that are commonly deficient in human diets:

- **Zinc (Zn)**: Critical for immune function and cellular growth. Zinc deficiency affects millions globally and is commonly addressed through zinc sulfate application in cereal crops.
- **Iron (Fe)**: Vital for hemoglobin formation. Iron deficiency anemia is prevalent among women and children; iron fertilizers like ferrous sulfate are used in biofortification efforts.

Role of Fertilizer Management in Nutrient Enrichment

Effective fertilizer management is crucial for successful agronomic biofortification. This involves:

- **Right Source**: Selecting appropriate and bioavailable forms of micronutrient fertilizers.
- **Right Dose**: Applying adequate quantities based on soil tests and crop requirements.
- **Right Time**: Timing applications to match crop growth stages for maximum uptake.
- **Right Method**: Choosing between soil, foliar, or seed treatments based on specific needs.

Integrated nutrient management strategies that combine organic and inorganic sources can also enhance the efficiency of biofortification practices.

Impact on Human Health and Nutritional Security

Biofortified crops have shown significant potential in improving nutritional status. For example:

- **Zinc-biofortified wheat** has been shown to improve zinc intake in rural populations.
- **Iron-biofortified rice and beans** help combat anemia, especially in women and children.
- **Selenium-enriched cereals** contribute to improved antioxidant activity and immunity.

Regular consumption of biofortified foods can lead to measurable health improvements, contributing to Sustainable Development Goals (SDGs) related to hunger, health and well-being.

Challenges and Limitations in Adoption

Despite its promise, agronomic biofortification faces several challenges:

- **Limited Awareness**: Farmers and consumers often lack knowledge about the benefits of biofortified crops.
- **Access to Inputs**: Quality micronutrient fertilizers are not always readily available or affordable.
- **Soil Constraints**: Micronutrient deficiencies in soils may limit uptake despite application.
- **Policy and Institutional Support**: Weak policy frameworks and limited extension services hinder large-scale adoption.

Overcoming these barriers requires coordinated efforts from governments, research institutions, NGOs, and the private sector.

Future Prospects and Policy Implications for Scaling Biofortification

To scale agronomic biofortification, future efforts should focus on:

- **Research and Development**: Investing in location-specific agronomic trials and innovative fertilizer formulations.
- **Capacity Building**: Training farmers, extension workers and input dealers.
- **Subsidy and Incentive Schemes**: Encouraging adoption through support mechanisms.
- **Public-Private Partnerships**: Leveraging resources and expertise for input supply, marketing and awareness campaigns.
- **Regulatory Frameworks**: Establishing standards and quality assurance systems for micronutrient fertilizers and biofortified produce.

With supportive policies and scientific backing, agronomic biofortification can become a mainstream strategy to address malnutrition sustainably.

Conclusion

Agronomic biofortification is a scientifically validated, cost-effective and scalable approach to combating micronutrient malnutrition. By leveraging fertilizer-based interventions, it enriches staple crops with essential nutrients, directly improving the nutritional status of vulnerable populations. As part of an integrated food system strategy, biofortification aligns with global goals for sustainable agriculture, food security and public health. With continued investment, research and policy support, agronomic biofortification can be a cornerstone of future strategies to eliminate hidden hunger and ensure nutritional well-being for all.

References

Paul, M., Thriveni, V., Niharika, M., Upadhyay, D. K., Kiro, D., Verma, A., & Patil, S. (2024). A review on Biofortification of Crops: A Nutritional Strategy for Combating Malnutrition. *European Journal of Nutrition and Food Safety*, *16*(11), 63-77.

Ofori, K. F., Antoniello, S., English, M. M., & Aryee, A. N. (2022). Improving nutrition through biofortification–A systematic review. *Frontiers in nutrition*, *9*, 1043655.

Wakeel, A., Farooq, M., Bashir, K., & Ozturk, L. (2018). Micronutrient malnutrition and biofortification: recent advances and future perspectives. *Plant micronutrient use efficiency*, 225-243.

Mayer, J. E., Pfeiffer, W. H., & Beyer, P. (2008). Biofortified crops to alleviate micronutrient malnutrition. *Current opinion in plant biology*, *11*(2), 166-170.

De Valença, A. W., Bake, A., Brouwer, I. D., & Giller, K. E. (2017). Agronomic biofortification of crops to fight hidden hunger in sub-Saharan Africa. *Global food security*, *12*, 8-14.

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Impacts of Climate Change on Forest Ecosystems: Challenges and Management Interventions

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Introduction

Forests play a critical role in maintaining the Earth's ecological balance by acting as carbon sinks, regulating water cycles, supporting biodiversity and providing livelihoods to millions of people worldwide. However, climate change poses significant threats to forest ecosystems. Rising temperatures, shifting precipitation patterns, increased frequency of extreme weather events and elevated atmospheric CO_2 concentrations are altering forest dynamics at an unprecedented pace. These changes threaten the ability of forests to deliver essential services, increase their vulnerability to degradation and exacerbate existing pressures such as deforestation and land-use change. Understanding the multifaceted impacts of climate change on forests and implementing effective management strategies is essential for maintaining ecosystem resilience and sustainability. This paper explores the impacts of climate change on forest dynamics, biodiversity, pest and disease prevalence, soil and hydrology and outlines adaptive and mitigation measures to address these challenges.

Climate Change and Its Effects on Forest Dynamics

Climate change influences forest ecosystems by modifying fundamental processes such as growth, productivity and species composition. In many regions, rising temperatures accelerate tree growth in the short term but may eventually lead to stress due to increased evapotranspiration, drought frequency and nutrient limitations. Changes in precipitation patterns affect soil moisture availability, impacting seedling survival, forest regeneration and the timing of ecological interactions.

Warming in boreal and temperate regions has triggered northward and upward shifts in species ranges, changing forest composition and potentially leading to mismatches in ecosystem functioning. In tropical forests, high temperatures and prolonged dry periods can reduce productivity and increase tree mortality. These alterations compromise forest stability and reduce their capacity to act as carbon sinks. Furthermore, changes in phenological events such as leaf emergence, flowering and fruiting affect interdependent species, disrupting food chains and altering community structures.

Biodiversity Loss and Species Vulnerability

Forest biodiversity is particularly vulnerable to climate-induced changes. Species adapted to specific climatic conditions may find it difficult to survive in altered habitats, especially in fragmented landscapes. Range shifts may lead to habitat contraction, genetic isolation and even extinction for less mobile or narrowly adapted species. Climate change can also increase the prevalence of invasive species, which outcompete native flora and fauna.

Species with limited dispersal abilities, such as many understory plants and small mammals, are at high risk. Mountain and island ecosystems, which harbor many endemic species are particularly susceptible. The loss of keystone species, organisms that have disproportionate ecological influence—can trigger cascading effects across trophic levels, destabilizing entire ecosystems. Conservation of biodiversity under climate change requires habitat connectivity, genetic conservation and adaptive management that prioritizes vulnerable ecosystems.

Increased Incidence of Pests, Diseases, and Wildfires

One of the most visible consequences of climate change is the rise in pest and disease outbreaks. Warmer temperatures and milder winters enable pests such as bark beetles, aphids and forest pathogens to expand their range, increase reproduction rates and survive year-round. These infestations can lead to large-scale tree mortality, reducing forest biomass and ecosystem productivity.

Similarly, the frequency, duration and intensity of wildfires have increased globally. Higher temperatures, extended drought periods and fuel accumulation create favorable conditions for severe fire events. Wildfires not only cause immediate loss of vegetation but also release stored carbon, reduce air quality and hinder post-fire regeneration. In Mediterranean, boreal and tropical savanna forests, wildfires have become more frequent, stressing ecosystems already vulnerable to climate-induced change.

Soil and Hydrological Alterations

Forests and soils are intricately connected, with forest vegetation influencing soil stability, organic matter input and microbial processes. Climate-induced changes affect soil moisture, temperature and organic matter decomposition. For instance, warming accelerates microbial respiration and decomposition rates, leading to reduced soil carbon stocks and increased CO_2 emissions.

Droughts led to reduced microbial activity and hinder nutrient cycling, impairing forest productivity and soil fertility. Furthermore, intense rainfall events increase surface runoff, erosion and sedimentation in nearby water bodies. Hydrologically, forests regulate water flow, reduce runoff and maintain water quality. Climate change disrupts these functions by altering precipitation regimes and increasing evapotranspiration, leading to reduced stream flows, altered groundwater recharge and increased erosion. These effects are particularly severe in mountainous and tropical forest regions where water regulation is critical.

Socio-Economic and Livelihood Impacts

Forest-dependent communities, especially in developing countries, face disproportionate risks from climate change. These communities rely on forests for food, fuelwood, medicine, building materials and income. Climate-driven forest degradation reduces the availability of these resources, exacerbating poverty, food insecurity and social vulnerability.

Timber production and ecosystem services such as ecotourism, non-timber forest products and carbon sequestration may also decline, affecting national economies and conservation programs. Indigenous knowledge systems, which have co-evolved with forest ecosystems, are under threat due to environmental changes. Moreover, climate-induced displacement from forested regions could lead to cultural loss and increased socio-political tensions. Adaptation strategies must be inclusive and culturally sensitive to ensure sustainable development and resilience of forest-reliant societies.

Adaptive Forest Management Strategies

Adapting forest management practices to climate change is essential for enhancing ecosystem resilience. Key strategies include:

- **Climate-Resilient Silviculture**: Adapting silvicultural techniques to promote structural and species diversity, reduce vulnerability to pests and drought and enhance natural regeneration.
- **Assisted Migration**: Introducing climate-adapted tree species or genotypes to regions where current species may not survive future climatic conditions.
- **Agroforestry and Mixed Plantations**: Integrating trees with crops or livestock to diversify land use, enhance soil health, increase income streams and buffer climatic variability.

- **Community-Based Management**: Empowering local communities to manage forest resources, incorporate traditional ecological knowledge and ensure equitable benefit-sharing.

These adaptive approaches can maintain ecological functions, enhance carbon stocks and support socio-economic sustainability under changing climate scenarios.

Mitigation Strategies through Forest Carbon Sequestration

Forests play a key role in mitigating climate change through carbon sequestration. Effective mitigation strategies include:

- **Afforestation and Reforestation**: Planting trees on degraded lands or previously deforested areas to enhance biomass and soil carbon storage.
- **REDD+ Initiatives**: The UN-backed Reducing Emissions from Deforestation and Forest Degradation (REDD+) mechanism provides financial incentives for conservation, sustainable forest management and carbon enhancement.
- **Agroforestry Systems**: Incorporating trees into farming systems can increase carbon storage while supporting livelihoods, biodiversity and food security.

By implementing these strategies, forests can contribute significantly to national climate action plans and the goals of the Paris Agreement, providing both mitigation and adaptation benefits.

Policy and Institutional Frameworks

Effective policy frameworks and institutional support are vital for promoting climate-resilient forest management. Key measures include:

- **Integration into National Climate Policies**: Mainstreaming Forest adaptation and mitigation strategies into Nationally Determined Contributions (NDCs) and climate action plans.
- **Legal and Regulatory Support**: Strengthening Forest laws and policies to address climate risks, clarify carbon rights and support sustainable forest use.
- **Capacity Building and Financing**: Providing training, resources and access to climate finance for forest managers, communities and institutions.
- **International Collaboration**: Participating in global platforms such as the United Nations Forum on Forests (UNFF), Convention on Biological Diversity (CBD) and UNFCCC to foster cooperation, technology transfer and funding.

Robust institutions and inclusive governance are essential for implementing climate-smart forest strategies at scale.

Future Research Needs and Technological Innovations

To address the complex challenges facing forests, research and innovation must focus on:

- **Climate Modeling**: Developing high-resolution models to predict species responses, forest transitions and climate thresholds.
- **Remote Sensing and GIS**: Using satellite imagery, drones and geospatial tools for monitoring forest health, biomass, fire risk and land-use changes.
- **Genomic Tools**: Identifying climate-resilient genotypes and promoting assisted breeding for adaptation.
- **Socio-Ecological Studies**: Investigating human-forest interactions, community adaptation practices and governance models to support policy-making.

Investments in science, innovation and data infrastructure can enhance adaptive capacity and inform real-time forest management decisions.

Conclusion

Climate change presents unprecedented challenges to forest ecosystems, threatening biodiversity, ecosystem services and the well-being of forest-dependent communities. However, through adaptive and science-based management, forests can remain resilient and continue to play a vital role in climate mitigation and adaptation. Integrated approaches—combining traditional knowledge, modern technologies, effective policies and community participation—are essential for safeguarding forests in a warming world. With concerted global and local efforts, it is possible to enhance forest resilience, maintain ecological integrity and ensure that forests continue to thrive and provide for future generations in the face of a changing climate.

References

Keenan, R.J., 2015. Climate change impacts and adaptation in forest management: a review. *Annals of forest science*, *72*, pp.145-167.

Kirilenko, A.P. and Sedjo, R.A., 2007. Climate change impacts on forestry. *Proceedings of the National Academy of Sciences*, *104*(50), pp.19697-19702.

Sohngen, B. and Tian, X., 2016. Global climate change impacts on forests and markets. *Forest Policy and Economics*, *72*, pp.18-26.
Keenan, R.J., 2015. Climate change impacts and adaptation in forest management: a review. *Annals of forest science*, *72*, pp.145-167.
Sedjo, R.A. and Solomon, A.M., 2016. Climate and forests. In *Greenhouse warming* (pp. 105-118). Routledge.

Islam, M.R., Jönsson, A.M., Bergkvist, J., Lagergren, F., Lindeskog, M., Mölder, M., Scholze, M. and Kljun, N., 2024. Projected effects of climate change and forest management on carbon fluxes and biomass of a boreal forest. *Agricultural and Forest Meteorology*, *349*, p.109959.

Wang, L., Wei, F., Tagesson, T., Fang, Z. and Svenning, J.C., 2025. Transforming forest management through rewilding: Enhancing biodiversity, resilience, and biosphere sustainability under global change. *One Earth*, *8*(3).

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Green Financing in the Context of Sustainable Forest Management

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Introduction

Forests are vital ecosystems that contribute significantly to environmental stability, biodiversity conservation and the livelihoods of millions of people worldwide. However, they are increasingly under threat due to deforestation, land-use change and unsustainable exploitation. Sustainable Forest Management (SFM) has emerged as a comprehensive approach to balancing ecological, social and economic functions of forests. One of the key enablers of SFM is green financing, which involves channeling funds into initiatives that promote environmental sustainability, including forest conservation. This paper explores the role of green financing in facilitating sustainable forest management, highlighting its mechanisms, impacts, challenges and prospects.

Concept of Green Financing

Green financing refers to structured financial mechanisms that promote environmental sustainability, reduce ecological risks and foster climate-resilient development. It includes various tools such as green bonds, carbon credits, sustainability-linked loans and investment in renewable resources. In the forestry sector, green financing is directed toward projects that conserve forest ecosystems, enhance carbon sequestration and support afforestation and reforestation efforts.

Key components of green finance include:

- **Green Bonds**: Debt instruments used to raise capital specifically for climate and environmental projects.
- **Carbon Finance**: Payments for reduced carbon emissions through forest conservation or afforestation.
- **Sustainability Funds**: Investments by public or private entities into environmentally-friendly projects.
- **Eco-labeling and Certification**: Incentives for sustainable timber harvesting practices.

Importance of Green Finance for Forest Ecosystems

Green financing is crucial for sustainable forest management due to the following reasons:

- **Biodiversity Conservation**: Green finance supports efforts to protect endangered species and maintain genetic diversity in forest ecosystems.
- **Climate Change Mitigation**: Forests act as carbon sinks; thus, financing afforestation and reduced deforestation projects helps mitigate climate change.
- **Watershed Protection and Soil Health**: Green investments in forest management also protect water catchments and reduce soil erosion.
- **Livelihood Support**: Financing community-based forest initiatives provides income and employment to forest-dependent communities.

Financing Instruments for Sustainable Forest Management

Several green finance instruments have been developed and adapted for forest conservation and sustainable use:

- **Payment for Ecosystem Services (PES)**: Under PES schemes, landowners or communities receive compensation for maintaining or enhancing forest ecosystem services.
- **REDD+ Program**: Launched by the UNFCCC, REDD+ (Reducing Emissions from Deforestation and Forest Degradation) incentivizes forest conservation in developing countries.
- **Green Climate Fund (GCF)**: Supports projects that promote low-emission and climate-resilient development, including forest conservation.
- **Public-Private Partnerships (PPPs)**: Collaborations between governments, NGOs and private investors facilitate funding for forest-related projects.

These mechanisms help bridge the funding gap in the forestry sector while ensuring environmental and social co-benefits.

Case Studies and Global Initiatives

Several countries and organizations have successfully implemented green financing in forest conservation:

- **India**: Through the CAMPA (Compensatory Afforestation Fund Management and Planning Authority) fund, resources are allocated for afforestation to compensate for diverted forest land.
- **Brazil**: The Amazon Fund, supported by Norway and Germany, provides financial support for projects that combat deforestation and promote SFM.
- **Indonesia**: Community-based forest management and green finance projects under the REDD+ initiative have shown measurable impact.
- **Africa**: The Congo Basin Forest Fund supports sustainable land use and reforestation projects through innovative financing.

These examples demonstrate how financial tools, when integrated with policy and institutional support, can drive effective forest conservation outcomes.

Policy Framework and Institutional Support

A robust policy environment is essential to promote green finance and its application in forestry. Key elements include:

- **National Forest Policies**: Countries need clear policy directives on forest conservation, funding mechanisms and sustainability standards.
- **Institutional Mechanisms**: Dedicated forest financing bodies and inter-agency coordination enhance fund mobilization and monitoring.
- **International Cooperation**: Participation in multilateral environmental agreements (MEAs) and access to global climate funds.
- **Fiscal Incentives**: Tax benefits, subsidies and insurance schemes for green projects.

Countries that integrate green financing into their development and climate strategies create an enabling environment for sustainable forest management.

Challenges and Barriers

Despite its potential, green financing in forestry faces several constraints:

- **Awareness and Capacity**: Limited knowledge about financial instruments among forest managers and community groups.
- **Regulatory Challenges**: Inadequate legal frameworks and enforcement of environmental standards.
- **Risk and Return Perception**: Investors often perceive forestry projects as high-risk with delayed returns.
- **Greenwashing**: Misuse of green finance labels without delivering actual environmental benefits.
- **Monitoring and Evaluation**: Difficulty in assessing the real impact of financed projects due to lack of data.

Addressing these barriers requires coordinated efforts among governments, financial institutions, and civil society.

Opportunities and Future Directions

Green financing is evolving, with emerging opportunities in technology, innovation and digital platforms:

- **Digital Finance**: Use of blockchain and fintech solutions for transparent and efficient fund flow and monitoring.
- **Community Financing Models**: Microfinance and cooperative-based funding for smallholder forest enterprises.
- **Eco-Tourism and Carbon Markets**: New income streams for forest conservation through eco-tourism and trading carbon credits.
- **Green Investment Platforms**: Online portals connecting investors with verified forest projects.
- **Climate-Smart Forestry**: Integration of resilience-building practices with sustainable land use.

Capacity building and stakeholder engagement are critical to harnessing these opportunities.

Conclusion

Green financing offers a promising pathway to achieve the goals of sustainable forest management by mobilizing the necessary resources and aligning them with environmental priorities. Through innovative financial mechanisms such as PES, REDD+ and green bonds and backed by institutional and policy support, it is possible to conserve forests while promoting economic development and social inclusion. However, to fully realize its potential, challenges such as regulatory gaps, market risks and capacity constraints must be addressed. Looking ahead, the synergy between finance, policy, technology and community participation will determine the success of green financing in ensuring resilient and sustainable forest ecosystems for future generations.

References

Dai, Y. and Chen, X., 2023. Evaluating green financing mechanisms for natural resource management: Implications for achieving sustainable development goals. *Resources Policy*, *86*, p.104160.

Holopainen, J. and Wit, M., 2008. Financing sustainable forest management.

Boscolo, M., Van Dijk, K. and Savenije, H., 2010. Financing sustainable small-scale forestry: lessons from developing national forest financing strategies in Latin America. *Forests*, *1*(4), pp.230-249.

Appanah, S., Shono, K., Mansur, E. and Krezdorn, R., 2006, November. Financing sustainable forest management: a growing challenge. In *Strategies and financial mechanisms for sustainable use and conservation of forests: experiences from Latin America and Asia. Proceedings of an inter-regional workshop, Chiang Mai, Thailand* (pp. 20-22).

Tegegne, Y.T., Cramm, M. and Van Brusselen, J., 2018. Sustainable forest management, FLEGT, and REDD+: exploring interlinkages to strengthen forest policy coherence. *Sustainability*, *10*(12), p.4841.

Martín-García, J. and Diez, J.J., 2012. Sustainable forest management: An introduction and overview. *Sustainable forest management–Current research*, pp.3-16.

Dörry, S. and Schulz, C., 2018. Green financing, interrupted. Potential directions for sustainable finance in Luxembourg. *Local Environment*, *23*(7), pp.717-733.

Sue, D., 2010, July. Facilitating financing for sustainable forest management in small islands developing states and low forest cover countries. An analytical report prepared by Indufor for the United Nations Forum on Forests, Country Case Study: Fiji. In *An analytical report prepared for the United Nations Forum on Forests Country case study: Fiji*.

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Integrated Disease Management Strategies for Sustainable Crop Protection

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Introduction

Agriculture is the cornerstone of food security and rural livelihoods, but its productivity is persistently challenged by plant diseases caused by fungi, bacteria, viruses and nematodes. These diseases can cause significant yield losses, ranging from 20% to 40% globally and even more under epidemic conditions. Traditional reliance on chemical pesticides, though initially effective, has led to adverse environmental effects, pesticide resistance and health concerns. In this context, Integrated Disease Management (IDM) emerges as a holistic and sustainable approach to crop protection that combines cultural, biological, chemical and genetic strategies. This paper explores the various components of IDM, their practical applications, benefits, challenges and the way forward for sustainable agriculture.

Concept and Components of Integrated Disease Management (IDM)

IDM refers to a strategic approach to managing plant diseases by integrating multiple control methods that are environmentally safe, economically viable and socially acceptable. The core objective is to reduce disease incidence and severity to manageable levels while minimizing dependence on chemical pesticides. The primary components of IDM include:

- **Cultural Practices**: Manipulation of farming practices to reduce disease incidence.
- **Host Plant Resistance**: Use of disease-resistant varieties.
- **Biological Control**: Exploiting natural enemies of pathogens.
- **Chemical Control**: Judicious use of fungicides and bactericides.
- **Mechanical and Physical Methods**: Techniques like soil solarization.

Each of these components works synergistically, making IDM a dynamic and adaptive strategy.

Cultural Practices in Disease Suppression

Cultural control forms the first line of defense in IDM. These practices are preventive and aim to create an unfavorable environment for pathogens:

- **Crop Rotation**: Alternating susceptible crops with non-host crops helps break the disease cycle. For instance, rotating tomato with cereals can reduce bacterial wilt.
- **Sanitation**: Removal of crop residues and weeds minimizes the source of inoculum.
- **Optimal Planting Time**: Adjusting sowing dates can help avoid peak periods of pathogen activity.
- **Proper Spacing and Irrigation Management**: Reduces humidity and improves air circulation, thereby limiting the spread of foliar diseases.
- **Organic Amendments**: Use of compost and farmyard manure enhances soil health and suppresses soil-borne pathogens.

Host Plant Resistance and Breeding Approaches

Genetic resistance is a cornerstone of IDM. Growing resistant varieties is cost-effective and environmentally friendly:

- **Conventional Breeding**: Developing resistant varieties through hybridization and selection. For example, blast-resistant rice varieties have significantly reduced yield losses in Asia.
- **Marker-Assisted Selection (MAS)**: Accelerates the breeding process by tagging resistance genes.
- **Genetic Engineering**: Transgenic crops with specific resistance genes, such as Bt cotton, have shown remarkable success.
- **Gene Editing Tools**: CRISPR-Cas9 and other tools offer precise resistance incorporation without introducing foreign DNA.

Continuous monitoring and development of resistant varieties are essential due to the evolving nature of pathogens.

Biological Control Agents and Biofungicides

Biological control uses living organisms to suppress disease-causing pathogens:

- **Fungal Biocontrol Agents**: *Trichoderma* species suppress soil-borne pathogens like *Rhizoctonia* and *Fusarium*.
- **Bacterial Antagonists**: *Pseudomonas fluorescens* and *Bacillus subtilis* produce antibiotics and siderophores that inhibit pathogen growth.
- **Mycorrhizal Fungi**: Enhance nutrient uptake and plant health, indirectly reducing disease susceptibility.
- **Commercial Bio fungicides**: Available in formulations for seed treatment, foliar application and soil amendment.

Biocontrol is eco-friendly and sustainable but may require specific environmental conditions for effectiveness.

Rational Use of Chemical Fungicides

Chemical fungicides are still important in IDM, especially when disease pressure is high. However, their use should be strategic:

- **Fungicide Rotation**: Alternating products with different modes of action to prevent resistance buildup.
- **Threshold-Based Application**: Applying only when disease reaches economic threshold levels.
- **Integration with Other Methods**: Combining fungicides with biocontrol agents or resistant varieties enhances effectiveness.
- **Systemic and Contact Fungicides**: Systemic fungicides offer longer protection but must be used judiciously.

Awareness and training on safe pesticide use are crucial to avoid misuse and environmental contamination.

Disease Forecasting and Decision Support Systems

Modern IDM incorporates forecasting tools and decision support systems to make timely and informed interventions:

- **Weather-Based Models**: Predict disease outbreaks based on temperature, humidity and rainfall.
- **ICT Tools**: Mobile apps and SMS alerts help farmers receive real-time disease warnings.
- **Remote Sensing and GIS**: Monitor large-scale disease spread for strategic planning.
- **AI and Machine Learning**: Used for image-based disease detection and risk assessment.

Such tools enhance the precision and effectiveness of IDM interventions.

Case Studies and Success Stories

Several crops and regions have demonstrated the successful implementation of IDM:

- **Rice (India)**: The combination of resistant varieties, biocontrol agents and reduced fungicide use has decreased sheath blight and blast.
- **Tomato (Africa)**: IDM strategies including solarization, crop rotatio and biopesticides reduced bacterial wilt incidence.
- **Cotton (USA)**: Integration of Bt cotton, crop rotation, and pheromone traps managed bollworm and fungal diseases effectively.

- **Potato (Europe)**: Forecasting models have significantly reduced fungicide sprays for late blight.

These cases show that IDM is practical and beneficial across diverse cropping systems.

Constraints and Challenges in IDM Adoption

Despite its benefits, IDM adoption faces several barriers:

- **Knowledge and Awareness**: Farmers often lack training in IDM principles.
- **Input Availability**: Limited access to quality biocontrol agents and resistant seeds.
- **Policy Gaps**: Lack of government incentives and regulatory frameworks for biopesticides.
- **Short-Term Focus**: Farmers prefer quick results from chemicals rather than long-term solutions.
- **Monitoring and Evaluation**: Difficulty in assessing IDM impact due to complex interactions among components.

Addressing these challenges requires coordinated efforts from policymakers, researchers and extension agencies.

Future Perspectives and Research Needs

To scale IDM adoption and enhance its impact, several areas require attention:

- **Region-Specific Packages**: Tailored IDM practices based on local agro-ecological conditions.
- **Innovation in Biocontrol**: Development of next-generation biopesticides with broader spectrum and shelf stability.
- **Climate-Resilient IDM**: Adapting IDM strategies to address climate-induced changes in disease patterns.
- **Capacity Building**: Farmer training programs and inclusion of IDM in agricultural curricula.
- **Policy Support**: Incentivizing adoption through subsidies, certification and market linkages.

Public-private partnerships and participatory research can further accelerate IDM adoption.

Conclusion

Integrated Disease Management is a vital strategy for achieving sustainable crop protection. By combining multiple control methods, it reduces disease pressure, minimizes chemical dependency and enhances environmental and human health. Successful implementation of IDM requires a systems-based approach involving farmers, researchers, extension agents and policymakers. With growing concerns over climate change, pesticide resistance and food security, IDM offers a resilient pathway to protect crops and ensure agricultural sustainability. Moving forward, investment in research, infrastructure and capacity-building is essential to mainstream IDM and reap its full benefits in global agriculture.

References

Khan, S. M., Ali, S., Nawaz, A., Bukhari, S. A. H., Ejaz, S., & Ahmad, S. (2019). Integrated pest and disease management for better agronomic crop production. *Agronomic Crops: Volume 2: Management Practices*, 385-428.

Khoury, W. E., & Makkouk, K. (2010). Integrated plant disease management in developing countries. *Journal of Plant Pathology*, S35-S42.

Abbas, M., Saleem, M., Hussain, D., Ramzan, M., Jawad Saleem, M., Abbas, S., ... & Parveen, Z. (2022). Review on integrated disease and pest management of field crops. *International Journal of Tropical Insect Science*, *42*(5), 3235-3243.

Haq, I. U., & Ijaz, S. (Eds.). (2020). *Plant disease management strategies for sustainable agriculture through traditional and modern approaches* (Vol. 13). Springer Nature.

Pandey, A. K., Sain, S. K., & Singh, P. (2016). A perspective on integrated disease management in agriculture. *Bio Bull*, *2*(2), 13-29.

Gurjar, M. S., Saharan, M. S., & Aggarwal, R. A. S. H. M. I. (2018). Integrated disease management practices for sustainable agriculture under ICM approach. *Integrated crop management practices for enhancing productivity resource use efficiency, soil health, and livelihood practices, eds AK Chaoudhary, RS Bana, V. Pooniya*, 113-120.

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Nanobiochar as a Climate-Smart Tool: Carbon Sequestration and GHG Mitigation Potential

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Introduction

Climate change presents a critical challenge to agriculture and global food security. Rising temperatures, erratic precipitation patterns and increasing greenhouse gas (GHG) concentrations are already impacting yields and threatening ecosystems. Agriculture contributes substantially to GHG emissions, primarily through soil management, livestock and fertilizer use. Methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) are the primary GHGs emitted from agricultural practices. Addressing this challenge calls for climate-smart agricultural technologies that can sequester carbon, reduce emissions and improve resource use efficiency.

One such emerging tool is **nanobiochar**, a nano-scale form of biochar. Unlike conventional biochar, nanobiochar possesses enhanced surface area, porosity and reactivity due to its smaller particle size and active functional groups. It is produced through physical, chemical, or biological methods from biomass waste. This paper discusses the synthesis, characteristics, mechanisms and applications of nanobiochar in carbon sequestration and GHG mitigation. It further highlights its role in enhancing soil quality, reducing emissions and promoting sustainable, climate-resilient agriculture.

Concept and Synthesis of Nanobiochar

Nanobiochar is derived from biochar by reducing its particle size to less than 100 nanometers. The conversion is done using various techniques such as high-energy ball milling, ultrasonication and hydrothermal treatment. The resulting material retains the carbon-rich structure of biochar but with greater surface area, reactivity and functional groups that interact with soil constituents.

The method of synthesis significantly affects the nanobiochar's physical and chemical characteristics:

- **Ball Milling**: Provides high mechanical stability and a large surface area suitable for sorption.
- **Sonication**: Ensures good dispersion in aqueous media, improving its interaction with soil.
- **Hydrothermal Carbonization**: Offers moderate synthesis conditions while controlling surface chemistry.
- **Green Synthesis**: Involves biologically mediated processes using microbes or enzymes to reduce biochar size in an environmentally friendly manner.

Feedstock selection (e.g., rice husk, wood chips, manure) and pyrolysis conditions (temperature, duration) also influence the quality, stability and functionality of the final nanobiochar.

Mechanisms of Carbon Sequestration Using Nanobiochar

Carbon sequestration by nanobiochar occurs through long-term stabilization of organic carbon in soils. Its nano-scale size allows better penetration into soil micropores and stronger interactions with soil minerals, creating stable organo-mineral complexes.

Nanobiochar contributes to carbon sequestration in multiple ways:

- **Physical Protection**: Enhances soil aggregation, shielding organic matter from microbial degradation.
- **Chemical Stabilization**: Functional groups bind organic compounds, reducing their decomposition.
- **Microbial Interactions**: Modifies microbial habitats and activity, lowering the rate of carbon mineralization.

Recent studies show that nanobiochar-treated soils can store 20–30% more carbon than untreated soils, with persistence over multiple cropping cycles. By increasing the soil's organic carbon pool and slowing down degradation, nanobiochar plays a pivotal role in drawing down atmospheric CO_2.

Mitigation of Greenhouse Gas (GHG) Emissions

Nanobiochar can significantly reduce agricultural GHG emissions, particularly N_2O, CH_4 and CO_2, by influencing microbial processes, nutrient availability and soil aeration.

- **Nitrous Oxide (N_2O)**: Nanobiochar adsorbs nitrate and ammonium, limiting their availability for microbial transformation. It also improves soil aeration, discouraging denitrification and favoring complete conversion of N_2O to inert nitrogen (N_2).
- **Methane (CH_4)**: In flooded conditions like paddy soils, nanobiochar raises redox potential and supports methane-consuming bacteria while suppressing methane-producing archaea.
- **Carbon Dioxide (CO_2)**: By stabilizing organic matter and reducing microbial respiration rates, nanobiochar decreases net CO_2 emissions. It also enhances microbial carbon use efficiency.

Empirical studies indicate a 20–40% reduction in GHG emissions in nanobiochar-amended soils compared to controls. Isotope tracing and gas flux monitoring have validated these effects in diverse agroecosystems.

Impact on Soil Properties and Ecosystem Functions

Nanobiochar's influence extends beyond carbon management. It modifies key soil physical, chemical and biological properties:

- **Soil pH Adjustment**: Raises pH in acidic soils, enhancing nutrient availability and microbial function.
- **Cation Exchange Capacity (CEC)**: Increased due to high surface area and functional groups, improving nutrient retention.
- **Water Holding Capacity**: Porous structure enhances moisture retention, especially valuable under drought stress.
- **Microbial Activity**: Supports beneficial soil microbes by providing carbon sources and habitat, enhancing nutrient cycling and plant growth.

Moreover, nanobiochar can immobilize heavy metals and reduce pollutant bioavailability, improving soil health and food safety. Its positive influence on root architecture, enzymatic activities and soil structure translates into better crop growth and resilience.

Field Studies and Case Examples

Field experiments globally support the benefits of nanobiochar:

- **India**: Trials in rice-wheat systems in Punjab showed a 25% reduction in CH_4 emissions and an 18% increase in soil carbon. Cotton fields in Gujarat exhibited improved disease resistance and irrigation efficiency.
- **China**: In loamy soils, nanobiochar suppressed N_2O emissions and enhanced microbial biomass carbon. Long-term experiments showed increased nutrient retention and crop yields.

- **USA**: Cornfields in the Midwest displayed improved nitrogen use efficiency and lower CO_2 emissions. Integrating nanobiochar with precision farming improved productivity and environmental outcomes.

These examples highlight that nanobiochar is effective across soil types and climates, provided that application methods are tailored to local conditions.

Potential Risks and Knowledge Gaps

Despite its benefits, nanobiochar poses certain risks:

- **Ecotoxicity**: Excessive application may disrupt microbial communities or affect soil fauna.
- **Leaching and Mobility**: Nanoparticles may migrate to groundwater or aquatic ecosystems, posing risks to aquatic life.
- **Lack of Regulation**: Absence of standardized guidelines for synthesis, application and safety monitoring.

Addressing these challenges requires rigorous risk assessments, lifecycle studies and transparent communication with stakeholders to ensure safe and sustainable use.

Policy Implications and Climate Smart Agriculture Integration

For broader adoption, nanobiochar must be embedded within climate-smart agriculture policies:

- **National Policies**: Inclusion in climate adaptation strategies and GHG inventories.
- **Economic Incentives**: Subsidies, carbon credits and public-private partnerships to support farmers.
- **Extension Services**: Farmer training, demonstration trials and educational programs.
- **Regulatory Frameworks**: Safety standards and certification for nanobiochar products.

These initiatives can bridge the gap between research and practice, ensuring responsible and widespread adoption.

Future Research Directions

- **Tailored Formulations**: Designing nanobiochar for specific crops, soil types, or climatic zones.
- **Sensor Integration**: Using remote sensing and AI to monitor impacts in real-time.
- **Green Synthesis**: Developing eco-friendly production methods using microbes or enzymes.
- **Multifunctionality**: Incorporating bioinoculants or nutrients for synergistic benefits.
- **Life Cycle Assessments (LCA)**: Evaluating environmental and economic outcomes from production to field application.

These research directions will strengthen the knowledge base and promote innovations that enhance the environmental and economic viability of nanobiochar.

Conclusion

Nanobiochar represents a transformative solution for climate-smart agriculture. Its nano-scale properties make it more effective than conventional biochar in sequestering carbon, mitigating greenhouse gas emissions and improving soil health. With positive impacts on nutrient retention, microbial activity and water use efficiency, nanobiochar aligns well with the principles of sustainable agriculture. However, its potential must be harnessed responsibly through robust research, regulatory frameworks, and farmer awareness programs. Future advancements, such as precision application and multifunctional nanobiochars, can further enhance its utility. As the global community seeks innovative solutions to climate change, nanobiochar stands out as a promising ally in the quest for resilient and low-carbon agricultural systems.

References

Sultan, H., Li, Y., Ahmed, W., Shah, A., Faizan, M., Ahmad, A., Abbas, H.M.M., Nie, L. and Khan, M.N., 2024. Biochar and nano biochar: Enhancing salt resilience in plants and soil while mitigating greenhouse gas emissions: A comprehensive review. *Journal of Environmental Management*, *355*, p.120448.

Kumar, N. V., Pallavi, K. N., Rajput, P., Bhargavi, B., Chandra, M. S., Chandana, P., ... & Rajput, V. D. (2025). Nano-Biochar: A promising tool for sustainable agriculture under climate change era. *SAINS TANAH-Journal of Soil Science and Agroclimatology*, *22*(1), 89-106.

Shyam, S., Ahmed, S., Joshi, S. J., & Sarma, H. (2025). Biochar as a Soil amendment: implications for soil health, carbon sequestration, and climate resilience. Discover Soil, 2(1), 18.

Sarma, H. H., Borah, S. K., Dutta, N., Sultana, N., Nath, H., & Das, B. C. (2024). Innovative approaches for climate-resilient farming: strategies against environmental shifts and climate change. *International Journal of Environment and Climate Change*, *14*(9), 217-241.

Altaf, M. T., Shaheryar, M., Liaqat, W., Jamil, A., Hayat, M., Hayat, H. S., ... & Baloch, F. S. (2025). Nanotechnology: A Smart Approach for Sustainable Agriculture Under Global Climate Change. In *Bioremediation and Nanotechnology for Climate Change Mitigation* (pp. 557-591). Springer, Singapore.

Jadhav, V., Ahire, B., Pawar, A., Roy, A., Kumar, A., Sharma, K., ... & Verma, R. (2025). Nanobiochar: A sustainable solution for environmental remediation. *Environmental Nanotechnology, Monitoring & Management*, 101061.

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Precision Agriculture and Smart Farming Technologies in Vegetable Cultivation

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Introduction

Vegetable cultivation plays a critical role in ensuring food and nutritional security, generating income and providing employment opportunities. However, traditional farming practices often lead to inefficient resource utilization, low productivity and increased environmental degradation. With increasing population pressure and climate variability, there is a growing need to enhance vegetable productivity in a sustainable manner. Precision agriculture and smart farming technologies have emerged as revolutionary approaches to transform vegetable cultivation, enabling farmers to make data-driven decisions and optimize the use of inputs such as water, fertilizers and pesticides.

Concept and Scope of Precision Agriculture

Precision agriculture (PA) refers to a farming management concept that uses digital technologies to monitor and optimize agricultural operations. The goal is to ensure that crops and soil receive exactly what they need for optimal health and productivity. PA encompasses a range of technologies, including:

- **Global Positioning Systems (GPS)**: For accurate field mapping and navigation.
- **Geographic Information Systems (GIS)**: To analyze spatial data and variability in the field.
- **Remote Sensing**: For assessing crop health, moisture levels and nutrient deficiencies.
- **Variable Rate Technology (VRT)**: For site-specific application of inputs.
- **Artificial Intelligence (AI)** and **Machine Learning (ML)**: For predictive analytics and decision-making support.

These tools enable precise monitoring and management of fields, helping to reduce waste and enhance productivity.

Smart Farming Technologies in Practice

Smart farming, a subset of precision agriculture, integrates advanced technologies to automate and enhance farming operations. In vegetable cultivation, the following smart technologies are being employed:

- **Drones and Unmanned Aerial Vehicles (UAVs)**: Used for aerial imaging, crop scouting, and spraying operations. Drones can quickly identify areas of stress or pest infestation.
- **Internet of Things (IoT) Devices**: Sensors placed in the field monitor soil moisture, temperature and nutrient levels in real-time.
- **Mobile Applications and Farm Management Software**: Provide farmers with data analysis, crop planning, and market access.
- **Automated Irrigation and Fertigation Systems**: These systems deliver water and nutrients based on crop needs, minimizing waste.
- **Smart Greenhouses**: Controlled environments using sensors and actuators to regulate temperature, humidity and light, thus enhancing year-round vegetable production.

Applications in Vegetable Cultivation

The integration of precision and smart technologies in vegetable farming has several practical applications:

- **Site-Specific Nutrient Management**: Sensors detect nutrient deficiencies and guide variable fertilizer applications to different field zones.
- **Efficient Irrigation**: Soil moisture sensors and automated irrigation systems ensure that vegetables receive optimal water, avoiding both waterlogging and drought stress.

- **Pest and Disease Management**: Image recognition and AI tools detect early signs of diseases and pests, allowing for timely and targeted interventions.
- **Precision Planting and Harvesting**: GPS-guided machinery ensures uniform planting, while robotic harvesters reduce labor costs and post-harvest losses.

Benefits of Smart Technologies in Vegetable Production

Adopting smart farming and precision technologies in vegetable cultivation offers numerous advantages:

- **Enhanced Yield and Quality**: Better crop monitoring and input management result in improved productivity and higher quality produce.
- **Resource-Use Efficiency**: Optimization of water, fertilizer and pesticide use reduces input costs and conserves natural resources.
- **Environmental Sustainability**: Reduced chemical usage and precise interventions lower environmental pollution and carbon footprints.
- **Economic Gains**: Higher efficiency translates to better returns on investment and improved livelihood for farmers.
- **Labor Efficiency**: Automation of routine tasks reduces labor dependency, especially during peak seasons.

Case Studies and Success Stories

Several success stories from India and abroad illustrate the transformative power of precision agriculture in vegetable farming:

- **India**: The Indian Council of Agricultural Research (ICAR) has promoted smart vegetable farming using sensors and mobile apps in states like Maharashtra and Karnataka. Farmers reported a 20-30% increase in yields and 25% reduction in input use.
- **Netherlands**: Known for its advanced greenhouse systems, Dutch vegetable farmers use AI-powered climate control and hydroponic systems to achieve high productivity with minimal land and water.
- **USA**: Vegetable growers in California use drone-based surveillance and variable rate irrigation to manage large farms efficiently.

These examples demonstrate that integrating smart technologies in vegetable farming can lead to remarkable productivity gains and sustainability.

Constraints and Challenges

Despite the benefits, the adoption of precision agriculture in vegetable farming faces several challenges:

- **High Initial Cost**: Many small and marginal farmers cannot afford the capital investment required for smart technologies.
- **Technical Knowledge**: Lack of awareness and training restricts the effective use of digital tools.
- **Connectivity Issues**: Inadequate internet and mobile coverage in rural areas hinder real-time data access.
- **Fragmented Land Holdings**: Small and scattered fields complicate the implementation of GPS-guided machinery.
- **Data Privacy and Security**: Concerns over data ownership and misuse limit farmer participation.

Policy Support and Institutional Framework

Governments and institutions must play a proactive role in promoting precision agriculture:

- **Government Schemes**: Initiatives like the Digital India Program, National e-Governance Plan in Agriculture (NeGP-A) and Sub-Mission on Agricultural Mechanization (SMAM) support digital and smart agriculture.
- **Public-Private Partnerships (PPP)**: Collaboration between agri-tech startups, research institutions and farmers are essential to scale innovation.
- **Capacity Building**: Training centers and extension services should focus on building farmers' skills in handling digital tools.
- **Financial Support**: Subsidies, low-interest loans and incentives can encourage the adoption of smart technologies among smallholders.

Future Prospects and Research Needs

To fully harness the potential of smart farming in vegetable cultivation, further research and development are required:

- **AI and Machine Learning**: Continued development of predictive models for disease outbreaks, irrigation scheduling and yield forecasting.
- **Tailored Technologies**: Custom solutions for region-specific crops and socio-economic conditions.
- **Affordable Tools**: Low-cost sensors and open-source software for broader accessibility.
- **Climate Resilience**: Developing smart systems that adapt to changing climate conditions and support sustainable production.
- **Digital Literacy**: Promoting digital education among farming communities, especially women and youth.

Conclusion

Precision agriculture and smart farming technologies represent a paradigm shift in vegetable cultivation, offering solutions to traditional challenges of productivity, resource-use efficiency and sustainability. By enabling data-driven decisions, automating farm operations and optimizing input use, these technologies can significantly enhance the profitability and resilience of vegetable farming. However, realizing their full potential requires overcoming financial, technical and infrastructural barriers. With robust policy support, research investments and inclusive capacity-building programs, precision vegetable farming can pave the way for a smarter, greener and more prosperous agricultural future.

References

Kırkaya, A. (2020). Smart farming-precision agriculture technologies and practices. *Journal of Scientific Perspectives*, *4*(2), 123-136.

Kumar, V., Singh, S., & Singh, B. (2022). Precision farming in vegetable crops: A review. *Progressive Agriculture*, *22*(1), 79-88.

Narayan, R., & Narayan, S. (2014). Precision farming in vegetables. *Precision Farming: A New Approach; Ram, T., Lohan, SK, Singh, R., Singh, P., Eds*, 383.

Maheswari, R., Ashok, K. R., & Prahadeeswaran, M. (2008). Precision farming technology, adoption decisions and productivity of vegetables in resource-poor environments. *Agricultural Economics Research Review*, *21*, 415-424.

Kaushik, P. (2021). Precision vegetable farming technologies: An update. *Technology in agriculture*, *155*.

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Role of Plant Genetic Diversity in Climate-Resilient Agriculture

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Introduction

Climate change poses one of the most pressing threats to global food security. Increasing temperatures, erratic rainfall patterns, frequent droughts and emerging pests and diseases are challenging the sustainability of agricultural systems. In this context, the role of plant genetic diversity becomes paramount. It is not only the raw material for crop improvement but also a buffer against environmental stresses. Harnessing and conserving this diversity is essential for developing climate-resilient agriculture capable of feeding an ever-growing population under changing climatic conditions.

Understanding Plant Genetic Diversity

Plant genetic diversity refers to the total number of genetic characteristics in the genetic makeup of a plant species. It exists at three levels:

- **Genetic variation within species** (intraspecific diversity): Differences among individuals of the same species, such as different rice or wheat varieties.
- **Genetic variation among species** (interspecific diversity): Variation found in related species that can be used in breeding programs.
- **Ecosystem diversity**: The interactions of plant species with other organisms and their environment.

This diversity arises from natural selection, mutation, recombination and human selection during the domestication and improvement of crops. The genetic traits found in wild relatives and traditional landraces often harbor resistance to pests, diseases and adverse environmental conditions, making them invaluable for modern plant breeding.

Importance of Genetic Diversity in Crop Improvement

Genetic diversity serves as the primary raw material for plant breeding. It allows breeders to select and combine favorable traits to develop improved crop varieties with higher yield potential, better quality and resilience to environmental stresses.

- **Stress Tolerance**: Crops bred from diverse genetic sources can exhibit improved tolerance to heat, drought, salinity and cold, which are increasingly prevalent due to climate change.
- **Pest and Disease Resistance**: Genetic diversity enhances resistance to evolving pathogens and pests, reducing dependence on chemical pesticides.
- **Yield Stability**: Varieties developed using diverse genetic backgrounds tend to be more stable in yield across environments and over seasons.

A notable example is the Green Revolution, where high-yielding wheat and rice varieties, developed using diverse germplasm, helped avert famine in Asia.

Role in Adapting to Climate Change

As global temperatures rise and weather patterns become more unpredictable, maintaining and utilizing plant genetic diversity is essential for adaptation:

- **Drought-Resilient Varieties**: Genetic traits for deep root systems, reduced stomatal conductance and osmotic adjustment can be selected to breed crops that withstand prolonged dry spells.
- **Flood Tolerance**: Rice varieties with the Sub1 gene have shown remarkable submergence tolerance during floods, minimizing crop loss.
- **Salinity Resistance**: Coastal areas facing sea-level rise benefit from salt-tolerant crop varieties, many of which are developed using traits from wild relatives.
- **Temperature Adaptation**: Varieties with traits for early maturity or heat tolerance can avoid damage from heatwaves and shortened growing seasons.

The development of climate-smart crops relies heavily on access to and understanding of genetic variation.

Conservation of Genetic Resources

To harness plant genetic diversity, it must first be conserved. There are two primary conservation strategies:

- **In Situ Conservation**: Preservation of plant species in their natural habitats, including wild relatives and traditional farming systems. Examples include biosphere reserves and on-farm conservation.
- **Ex Situ Conservation**: Storage of genetic material in genebanks, seed vaults, botanical gardens and tissue culture repositories. Notable genebanks include the Svalbard Global Seed Vault in Norway and national repositories maintained by agricultural research organizations.

Conservation efforts must be dynamic, with regular regeneration, characterization and documentation of accessions to ensure they remain viable and useful for future breeding programs.

Traditional Knowledge and Landraces

Indigenous farmers have long played a critical role in developing and maintaining plant genetic diversity. Landraces, or traditional varieties, are genetically diverse and adapted to specific agro-ecological zones. These varieties often possess unique traits such as drought tolerance, pest resistance and nutritional quality.

- **Traditional Selection**: Farmers have historically selected seeds based on performance, creating resilient and locally adapted varieties.
- **Participatory Breeding**: Involving farmers in modern breeding programs ensures that new varieties meet local needs and gain quicker adoption.
- **Nutritional Security**: Landraces like colored maize, millets and pulses are often richer in micronutrients, addressing hidden hunger.

Preserving traditional knowledge systems is vital for maintaining biodiversity and enhancing climate resilience.

Biotechnological Interventions and Genomic Tools

Advancements in molecular biology and genomics have revolutionized our ability to explore and utilize plant genetic diversity:

1. **Marker-Assisted Selection (MAS)**: Allows for the rapid identification of desirable traits in breeding populations, reducing breeding cycles.
2. **Genome-Wide Association Studies (GWAS)**: Enable the discovery of genes linked to complex traits like drought tolerance or disease resistance.
3. **Genomic Selection (GS)**: Uses genome-wide markers to predict the performance of breeding lines, enhancing selection accuracy.
4. **CRISPR/Cas9 Gene Editing**: Provides precise tools to edit genes for stress tolerance, nutritional enhancement and productivity.

These tools accelerate the development of improved crop varieties and broaden the scope of diversity utilization.

Challenges in Utilizing Genetic Diversity

Despite its importance, several challenges hinder the optimal use of plant genetic diversity:

1. **Genetic Erosion**: Replacement of traditional varieties with high-yielding monocultures leads to the loss of unique traits.
2. **Limited Access to Germplasm**: Legal, technical and policy barriers often restrict the sharing and exchange of genetic resources.
3. **Inadequate Characterization**: Many conserved accessions lack detailed information about their traits, limiting their use.
4. **Climate-Induced Habitat Loss**: Wild relatives are under threat due to habitat destruction, requiring urgent conservation efforts.

Overcoming these challenges requires global cooperation, funding and strong policy support.

Policy and Institutional Support

Strengthening the conservation and utilization of genetic resources necessitates enabling policies and robust institutions:

- **International Treaties**: Agreements like the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) facilitate germplasm exchange and benefit-sharing.
- **National Programs**: Countries must invest in national genebanks, research institutions, and farmer-support programs.
- **Public-Private Partnerships**: Collaboration between public research institutes and private seed companies can accelerate varietal development.
- **Incentives for Conservation**: Farmers who maintain landraces and biodiversity should be supported through seed banks, buy-back schemes and recognition programs.

Integrating biodiversity objectives into national agricultural policies is essential for sustainable and climate-resilient farming.

Conclusion

Plant genetic diversity is the cornerstone of sustainable agriculture and food security in the face of climate change. Its role in developing climate-resilient crops, conserving traditional knowledge and enhancing nutritional security cannot be overstated. The successful integration of traditional breeding knowledge with modern genomic tools has unlocked unprecedented opportunities to utilize this diversity. However, the preservation and effective use of this genetic wealth require coordinated action among governments, researchers and farmers. Strong policy frameworks, technological innovations and inclusive community participation will ensure that the rich genetic legacy of plants is harnessed to build a resilient agricultural future for generations to come.

References

Munawar, S., ul Qamar, M. T., Mustafa, G., Khan, M. S., & Joyia, F. A. (2020). Role of biotechnology in climate resilient agriculture. *Environment, climate, plant and vegetation growth*, 339-365.

Banga, S. S., & Kang, M. S. (2014). Developing climate-resilient crops. *Journal of Crop Improvement*, *28*(1), 57-87.

Mba, C., & Ogbonnaya, F. C. (2022). Utilizing plant genetic resources to develop climate resilient crops. In *Agricultural biotechnology, biodiversity and bioresources conservation and utilization* (pp. 373-404). CRC Press.

Bakala, H. S., Singh, G., & Srivastava, P. (2020). Smart breeding for climate resilient agriculture. In *Plant breeding-current and future views*. IntechOpen.

Li, X., Li, Y., Sun, Y., Li, S., Cai, Q., Li, S., ... & Zhang, J. (2025). Integrating Genetic Diversity and Agronomic Innovations for Climate-Resilient Maize Systems. *Plants*, *14*(10), 1552.

Singh, A. P., Pandey, P. K., & Joshi, R. P. (2024). Harnessing Genetic Diversity for Climate-Resilient Maize: A Comprehensive Review. *Journal of Applied Biology and Agriculture*, *1*(1), 21-28.

Uprety, D. C., Reddy, V. R., Mura, J. D., Uprety, D. C., Reddy, V. R., & Mura, J. D. (2019). Climate Resilient Agriculture. *Climate Change and Agriculture: A Historical Analysis*, 59-66.

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Importance of Floriculture in Hilly Regions and Women's Empowerment

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Introduction

Floriculture, the cultivation of flowering and ornamental plants for gardens, landscapes and floral arrangements, has emerged as a rapidly expanding segment of horticulture worldwide. In hilly and mountainous regions, where traditional agriculture often struggles due to limited arable land, unpredictable climatic conditions and poor connectivity, floriculture presents a viable alternative. Not only does it provide a steady and high-value source of income, but it also supports biodiversity, eco-tourism and the local economy. Importantly, floriculture offers unique avenues for the socio-economic empowerment of women, especially in rural areas, by enabling them to participate actively in agriculture-related entrepreneurship. This paper explores the potential of floriculture in hilly regions and examines how it contributes to women's empowerment, while also highlighting the challenges and policy interventions needed for sustainable growth.

Potential of Floriculture in Hilly Regions

Hilly regions possess distinctive Agro-climatic advantages that make them suitable for floriculture. The moderate to cool temperatures, well-drained soils and ample rainfall in these areas allow for the cultivation of a wide range of flowers.

1. **Agro-Climatic Advantage**: Unique climatic conditions support year-round production of high-value flowers like roses, orchids, gladiolus, carnations and lilies.
2. **Diverse Flora**: Hilly regions often harbor endemic and exotic plant species, which can be harnessed for commercial flower cultivation.
3. **Export Potential**: Flowers from high altitudes are in demand both nationally and internationally due to their superior quality and longevity.
4. **Eco-Tourism Synergy**: Scenic flower farms attract tourists and can be integrated with agro-tourism ventures to provide additional revenue.
5. **Post-Harvest Utility**: Opportunities in flower processing such as making essential oils, potpourri and dried flower crafts enhance value addition.

Economic Empowerment of Women through Floriculture

Women in hilly regions are often the backbone of household-level agriculture. Floriculture offers them numerous pathways to improve household income and achieve financial independence.

1. **Home-Based Enterprises**: Women can manage floriculture around their homes, especially in kitchen gardens, backyards, or terrace spaces.
2. **Low Investment, High Return**: Compared to many other farming practices, the input cost is lower while the returns—especially for cut flowers—are considerably high.
3. **Market Access and SHGs**: Women's Self-Help Groups (SHGs) and cooperatives help in collective

marketing, reducing dependency on middlemen.

4. **Diversified Income Streams**: Women can engage in producing cut flowers, seeds, garlands, decorative plants and arrangements for events.
5. **Linkages with Retail and Events**: Urban demand for flowers in retail, hospitality and ceremonial events opens avenues for rural women entrepreneurs.

Social and Psychological Empowerment

Beyond economic gains, floriculture provides psychological, educational and social upliftment for women in hilly areas.

1. **Improved Self-Confidence**: Income-generating activities improve women's self-esteem and decision-making ability within families.
2. **Training and Skill Development**: Through workshops and extension services, women learn technical skills like propagation, nursery management, pest control and floral design.
3. **Leadership and Participation**: Women involved in floriculture often lead SHGs, contribute to Panchayati Raj institutions and participate in policy dialogues.
4. **Social Recognition**: Successful women floriculturists become role models in their communities, encouraging more female participation.
5. **Reduction in Male Migration**: Employment opportunities for women in floriculture reduce the need for male family members to migrate, stabilizing households.

Case Studies and Success Stories

Several Indian states have demonstrated successful integration of floriculture into women-led enterprises in hilly regions.

- **Sikkim**: With its organic agriculture policy, Sikkim has empowered women's SHGs in commercial floriculture, especially in orchid cultivation.
- **Uttarakhand**: The state government and NGOs have supported women cooperatives in hill districts like Almora and Chamoli to adopt floriculture under protected cultivation.
- **Himachal Pradesh**: KVKs and NABARD-assisted projects have facilitated seasonal flower cultivation by women, resulting in consistent income and local employment.

These examples emphasize the importance of institutional support, training and market linkages in scaling floriculture.

Challenges and Constraints

Despite its benefits, floriculture in hilly regions faces multiple challenges:

1. **Infrastructure Gaps**: Lack of cold storage, rural roads and packaging facilities increases post-harvest losses.
2. **Market Fluctuation**: The perishable nature of flowers combined with inconsistent pricing creates income instability.
3. **Limited Extension Services**: There are insufficient experts and training programs dedicated to floriculture in remote hilly areas.
4. **Gender Disparities**: Societal norms may restrict land ownership, finance access and mobility for women, limiting their ability to scale operations.
5. **Climate Risks**: Unpredictable weather patterns, frost and hailstorms in hilly regions can severely damage flower crops.

Policy Recommendations and Strategic Interventions

To ensure floriculture contributes effectively to women's empowerment and regional development, targeted interventions are required:

1. **Skill Enhancement**: Regular training on new varieties, floral design, greenhouse technology and value addition.

2. **Infrastructure Support**: Development of rural market hubs, floriculture-specific cold chains and mobile collection vans.
3. **Credit and Insurance Access**: Gender-sensitive credit schemes and crop insurance tailored for flower growers.
4. **Incentivizing SHGs**: Government support for collective marketing, logistics and certification (e.g., organic, GI tags).
5. **Public-Private Partnerships**: Collaboration with private firms for contract farming, export channels and online flower retail.

Environmental and Sustainable Aspects

Floriculture, if practiced responsibly, can enhance environmental sustainability in sensitive hilly terrains:

1. **Soil and Water Conservation**: Many flower crops improve ground cover and reduce erosion risks.
2. **Pollinator Support**: Flowering plants serve as habitats for bees and butterflies, aiding local biodiversity.
3. **Promotion of Organic Cultivation**: Organic floriculture avoids excessive chemical usage and preserves ecological balance.
4. **Agroecological Landscaping**: Integrating flowers with fruit orchards or terrace farming improves aesthetics and yields.

Future Prospects and Innovations

Floriculture holds vast potential if combined with innovation and technology.

1. **Digital Marketing and E-Commerce**: Mobile apps and platforms can connect rural floriculturists directly with urban buyers.
2. **Floral Processing Units**: Facilities for producing essential oils, perfumes and potpourri offer additional income avenues.
3. **Greenhouse Floriculture**: Protected cultivation enables off-season production and better-quality control.
4. **Integration with Eco-Tourism**: Flower shows, festivals and guided garden tours attract visitors and enhance income.
5. **Educational Modules**: Including floriculture in school and college curricula to foster youth and women entrepreneurship.

Conclusion

Floriculture in hilly regions has emerged as a promising, eco-friendly and economically rewarding alternative to conventional farming. When aligned with women's participation, it serves as a robust model for rural development, gender equity and sustainable livelihoods. Despite challenges, the synergistic benefits to the environment, economy and society make floriculture a strategic sector deserving greater attention and investment. With proper policy support, institutional backing and community engagement, floriculture can truly bloom as a transformative force for women in hilly regions, fostering inclusive and resilient development.

References

Singh, P. (2008). Floriculture as an Emerging Tool for Women Empowerment: A Case Study of Himachal Pradesh. *Science*, *48*(2).

Patel, K. M., Chaudhary, M., & Chaudhary, M. (2018). Floriculture increasing women empowerment and livelihood development. In *Gujarat J Extension Educ. Special Issue on National Seminar*.

Hadiya, M. (2020). *Role of Floriculture in Women Empowerment in Kashmir Valley-A case study* (Doctoral dissertation, SKUAST Kashmir).

Agoramoorthy, G., & Hsu, M. J. (2012). Impact of floriculture development enhances livelihood of India's rural women. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, *113*(1), 69-76.

Patel, K. M., Chaudhary, M., & Chaudhary, M. (2018). Floriculture increasing women empowerment and livelihood development. In *Gujarat J Extension Educ. Special Issue on National Seminar*.

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Soil Organic Carbon Dynamics under Different Cropping Systems

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Introduction

Soil organic carbon (SOC) is a fundamental component of soil health, playing a critical role in maintaining soil fertility, structure and biological activity. It also serves as a significant reservoir in the global carbon cycle, influencing greenhouse gas emissions and climate change. The management of SOC is vital for sustainable agriculture, especially as land degradation, nutrient depletion and global warming continue to threaten food security. Cropping systems influence SOC dynamics through the quantity and quality of organic inputs, soil disturbance and biological activity. This paper explores how different cropping systems affect SOC content, transformation and sequestration and offers management strategies to enhance SOC for long-term agricultural sustainability.

Concept of Soil Organic Carbon (SOC)

SOC refers to the carbon component of organic compounds found in soil, including plant and animal residues at various stages of decomposition, soil organisms and humus. It is a part of soil organic matter (SOM) and can be divided into:

- **Active pool:** Rapidly decomposable, contributes to short-term nutrient supply.
- **Slow pool:** Intermediate turnover, provides medium-term fertility.
- **Passive pool:** Very stable, important for long-term carbon storage.

SOC acts as a nutrient reservoir, improves soil structure and water retention, and supports microbial life, all of which are essential for sustainable crop production.

Cropping Systems and Their Influence on SOC

Cropping systems refer to the type and sequence of crops grown and their management practices. They significantly influence the input and decomposition of organic matter. Major cropping systems include:

1. **Monocropping:** Repeatedly growing a single crop. Tends to reduce SOC due to low diversity and high soil disturbance.
2. **Crop rotation:** Alternating crops in a sequence. Enhances SOC by varying residue quality and root biomass.
3. **Intercropping:** Growing two or more crops together. Promotes continuous organic inputs.
4. **Agroforestry:** Integration of trees with crops. Significantly boosts SOC through litterfall and root turnover.
5. **Conservation agriculture:** Includes minimum tillage, residue retention and cover cropping. Best suited for SOC buildup.

Mechanisms of SOC Accumulation and Depletion

SOC dynamics involve a balance between carbon inputs (e.g., root exudates, residues, manure) and outputs (e.g., mineralization, erosion). Key processes include:

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1. **Photosynthesis and residue return:** Plant growth fixes atmospheric CO2, contributing biomass to soil.
2. **Decomposition:** Microbial breakdown releases nutrients and CO2.
3. **Humification:** Conversion of organic matter into stable humus.
4. **Erosion and leaching:** Physical losses reduce SOC stock.

SOC accumulation is favored when organic inputs exceed decomposition and physical losses.

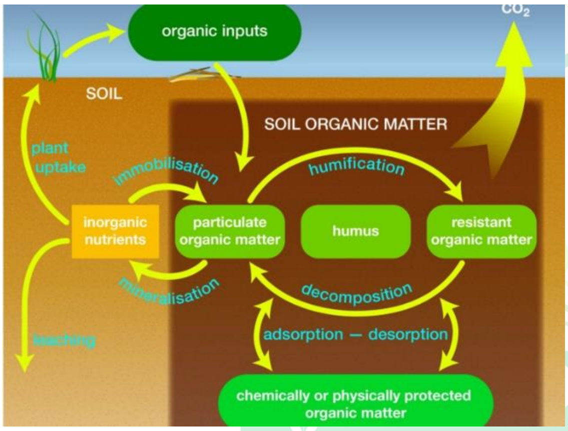

Figure 1: Mechanisms of SOC Accumulation and Depletion

SOC Dynamics in Major Cropping Systems

1. Cereal-based Systems:

Rice-wheat and maize-wheat systems are common in Asia. Continuous cultivation without organic inputs leads to SOC decline. Inclusion of legumes and residue retention improves SOC.

2. Legume-based Systems:

Soybean-wheat and pulse-based rotations contribute biological nitrogen and diverse root exudates, enhancing SOC.

3. Horticultural Systems:

High-value crops often rely on chemical fertilizers. Integrating organic manures, compost and cover crops helps maintain SOC.

4. Organic Farming Systems:

Rely on compost, green manures and crop residues. These systems generally report higher SOC due to consistent organic inputs.

5. Conservation Agriculture Systems:

No-till, residue retention and diversified cropping promote higher SOC sequestration by minimizing disturbance and enhancing biomass input.

Role of Crop Residue Management and Tillage

Tillage accelerates organic matter decomposition and SOC loss. Conversely, reduced or no-till systems:

- Preserve surface residues.
- Enhance soil structure and moisture retention.
- Encourage microbial and faunal activity.

Residue management is equally vital. Incorporating or retaining residues on the field increases SOC, whereas burning leads to carbon loss and environmental damage.

Influence of Crop Diversification and Rotation

Diverse cropping systems improve SOC by:

- Increasing organic matter inputs from various root and shoot biomasses.
- Promoting microbial diversity and soil biological activity.
- Enhancing nutrient cycling.

For example, rice-legume-wheat rotations have shown increased SOC compared to continuous rice or wheat.

Microbial Activity and SOC Transformation

Microorganisms decompose plant residues and facilitate SOC stabilization. Diverse and active microbial populations:

- Transform labile carbon into humus.
- Improve nutrient availability.
- Form soil aggregates that protect SOC from oxidation.

Cropping systems that promote microbial diversity (e.g., those with legumes or reduced tillage) tend to have more stable SOC.

Climate Change and SOC under Cropping Systems

Climate change affects SOC through altered temperature, precipitation and CO2 levels. Elevated temperatures may increase decomposition rates, reducing SOC. Drought reduces biomass input. However, elevated CO2 may enhance crop growth and residue production, increasing SOC. Cropping systems that enhance resilience, such as agroforestry or cover cropping, buffer these effects.

Measurement and Monitoring of SOC

Common methods for SOC estimation include:

- Walkley-Black Method: Wet oxidation; cost-effective but less accurate.
- Dry Combustion: Using CHNS analyzers; precise but expensive.
- Remote Sensing and GIS: Emerging tools for large-scale SOC assessment.

Long-term field experiments are crucial to monitor SOC trends under different systems.

Management Strategies for SOC Enhancement

To improve SOC in cropping systems, the following practices are recommended:

- Residue retention and mulching
- Incorporation of green manures and compost
- Adoption of conservation tillage
- Inclusion of legumes in rotation
- Cover cropping and intercropping
- Agroforestry integration
- Balanced fertilization

Such practices not only improve SOC but also enhance overall soil health and crop productivity.

Challenges and Constraints

Despite the benefits, several challenges exist:

- Lack of awareness and training on SOC management.
- Short-term focus of farmers due to market pressure.
- Land fragmentation and labor shortages.
- Absence of policy incentives for SOC enhancement practices.
- Climate variability affecting biomass production.

Research Gaps and Future Directions

Future research should focus on:

- Developing region-specific models for SOC prediction.
- Assessing long-term impacts of diverse systems.
- Exploring microbial and root-level contributions to SOC.
- Studying SOC dynamics under climate-resilient cropping systems.
- Evaluating economic benefits of SOC-oriented practices.

Integration of digital tools like remote sensing, machine learning and decision support systems can aid in precise SOC monitoring and management.

Conclusion

Soil organic carbon is a key indicator of soil health and sustainability in agricultural systems. Cropping systems have a profound impact on SOC levels, influencing both carbon sequestration and soil productivity. Practices such as crop diversification, residue management, reduced tillage and inclusion of legumes and cover crops can significantly improve SOC stocks. While challenges remain, strategic research, policy support and farmer education can enable widespread adoption of SOC-enhancing practices. Maintaining and improving SOC under different cropping systems is essential for climate-smart agriculture, sustainable food production and environmental conservation.

References

Chan, K. Y., Conyers, M. K., Li, G. D., Helyar, K. R., Poile, G., Oates, A., & Barchia, I. M. (2011). Soil carbon dynamics under different cropping and pasture management in temperate Australia: Results of three long-term experiments. *Soil Research*, *49*(4), 320-328.

Parenti, A., Zegada-Lizarazu, W., Pagani, E., & Monti, A. (2022). Soil organic carbon dynamics in multipurpose cropping systems. *Industrial Crops and Products*, *187*, 115315.

Coumar, M. V., Kundu, S., Saha, J. K., Rajendiran, S., Dotaniya, M. L., Karthikeyan, K., & Patra, A. K. (2020). Soil carbon dynamics, carbon budget and its relationship with crop yield under different cropping systems in Vertisols of Central India. *Indian journal of agricultural sciences*, *90*(1), 123-7.

Swarup, A., & Singh, M. (2009). Soil carbon dynamics under intensive cropping systems. *Journal of the Indian Society of Soil Science*, *57*(4), 469-476.

Organic carbon cycling in soil. https://soilqualityknowledgebase.org.au/soil-organic-matter/

Soler, C. T., Bado, V. B., Traore, K., Bostick, W. M., Jones, J. W., & Hoogenboom, G. (2011). Soil organic carbon dynamics and crop yield for different crop rotations in a degraded ferruginous tropical soil in a semi-arid region: a simulation approach. *The Journal of agricultural science*, *149*(5), 579-593.

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Green Manuring for Soil Fertility Improvement

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Introduction

Sustainable agriculture aims to maintain and enhance soil fertility, crop productivity and environmental quality. One of the time-tested and eco-friendly practices that has gained renewed attention is green manuring. Green manuring involves the cultivation of specific crops, primarily legumes, which are incorporated into the soil while still green to enrich it with organic matter and essential nutrients. The practice is particularly significant in improving soil health, enhancing microbial activity, conserving moisture and promoting sustainable farming systems. As concerns about soil degradation, excessive chemical fertilizer use and environmental pollution grow, green manuring emerges as a low-cost, sustainable solution. This paper explores the types, benefits, challenges and future prospects of green manuring in the context of improving soil fertility.

Concept and Importance of Green Manuring

Green manuring refers to the practice of growing and plowing under green plants to improve soil fertility and organic content. Typically, leguminous crops like sunn hemp (*Crotalaria juncea*), dhaincha (*Sesbania aculeata*) and mung bean (*Vigna radiata*) are used due to their ability to fix atmospheric nitrogen through symbiosis with Rhizobium bacteria.

The key objectives of green manuring include:

1. Enrichment of the soil with organic matter.
2. Improvement in soil structure, aeration and water-holding capacity.
3. Enhancement of soil microbial biodiversity.
4. Reduction in soil erosion and nutrient leaching.
5. Supplementation of essential nutrients, especially nitrogen.

Types of Green Manure Crops

Green manure crops can be broadly classified into two categories:

a. In-situ green manuring:

This involves growing green manure crops on the same field where they will be incorporated. Examples include:

- Sunn hemp (*Crotalaria juncea*)
- Dhaincha (*Sesbania aculeata*)
- Cowpea (*Vigna unguiculata*)
- Berseem (*Trifolium alexandrinum*)
- Cluster bean (*Cyamopsis tetragonoloba*)

b. Ex-situ or bio-mulching:

In this method, green plants are grown elsewhere, harvested and then applied to the target field. Common materials include:

- Weeds
- Grasses
- Leguminous prunings

These crops not only supply organic matter but also help recycle nutrients within the system. Selection of appropriate green manure crops depends on regional Agro-climatic conditions, cropping patterns and soil type.

Soil Fertility Enhancement Through Green Manuring

Green manure crops improve soil fertility in several ways:

a. Nitrogen Fixation:

Leguminous green manure crops fix atmospheric nitrogen through symbiosis with Rhizobium bacteria. This biological nitrogen fixation can contribute 40-100 kg N/ha, reducing the need for synthetic nitrogen fertilizers. In tropical and subtropical regions, nitrogen fixation can be as high as 150 kg N/ha under optimal conditions.

b. Organic Matter Addition:

Upon decomposition, green manure crops add organic matter to the soil, improving its physical properties, such as structure, porosity and water-holding capacity. Organic matter also serves as an energy source for soil microbes and helps build stable soil aggregates.

c. Nutrient Recycling:

Green manure crops absorb nutrients from deeper soil layers and return them to the topsoil when decomposed, making them available to subsequent crops. This helps maintain a balanced nutrient profile in the rhizosphere.

d. Microbial Activity:

The added organic matter promotes microbial diversity and activity, enhancing nutrient cycling and soil health. Microorganisms involved in decomposition help convert organic nutrients into plant-available forms.

e. Weed and Pest Suppression:

Some green manure crops produce allelopathic compounds that suppress weeds and soil-borne pathogens. This contributes to a healthier crop environment and reduces dependency on chemical control measures.

Role in Soil Physical, Chemical, and Biological Properties

Green manuring positively influences various soil properties:

Physical Properties:

- Improves soil texture and aggregation
- Enhances water infiltration and retention
- Reduces compaction and crusting
- Aids in erosion control through increased ground cover

Chemical Properties:

- Increases soil organic carbon and nutrient availability
- Buffers soil pH, making it more favorable for nutrient uptake
- Improves cation exchange capacity (CEC), enhancing nutrient retention

Biological Properties:

- Enhances microbial biomass and enzymatic activity
- Stimulates beneficial soil fauna such as earthworms
- Encourages symbiotic and free-living nitrogen fixers
- Boosts biological nitrogen and phosphorus availability

These improvements collectively create a more resilient and productive soil ecosystem, especially in degraded or nutrient-poor soils.

Green Manuring in Cropping Systems

Green manuring can be integrated into multiple cropping systems to enhance sustainability:

a. Rice-based systems:

Green manuring with dhaincha or sunn hemp before rice transplantation significantly improves soil nitrogen content and rice yields. This practice also enhances soil puddling and reduces weed pressure.

b. Pulse-based systems:

Incorporation of legume residues enriches the soil and benefits subsequent cereal crops. Pulses like urad and mungbean act as short-duration green manures in rotations.

c. Organic farming systems:

Green manures are essential components, providing nutrients and suppressing weeds without synthetic inputs. Their use aligns with organic certification standards.

d. Intercropping systems:

Green manure legumes can be intercropped with main crops, providing dual benefits of biomass and ground cover. They also help in reducing inter-row weed growth and conserving soil moisture.

e. Horticulture and Agroforestry systems: Green manures like cowpea and mungbean are used between tree rows to improve soil fertility and reduce runoff. They play a vital role in sustaining long-term orchard productivity.

Environmental and Economic Benefits

Environmental Benefits:

1. Reduces greenhouse gas emissions by minimizing chemical fertilizer use
2. Enhances carbon sequestration in soils
3. Controls weeds and pests naturally
4. Protects water bodies from nutrient runoff
5. Restores degraded lands and enhances soil resilience to climate stress

Economic Benefits:

1. Decreases input costs on synthetic fertilizers
2. Improves soil productivity and crop yields in the long term
3. Reduces the cost of soil amelioration practices
4. Enhances profitability for small and marginal farmers
5. Supports low-input agriculture systems, increasing accessibility for resource-poor farmers

When adopted on a larger scale, green manuring contributes to national food security goals by enhancing the sustainability of crop production systems.

Challenges and Limitations

Despite its advantages, green manuring faces several constraints:

1. **Land and time availability:** Farmers may hesitate to allocate land and time for non-commercial green manure crops.
2. **Water requirement:** Some green manure crops require irrigation, which can be a constraint in dry areas.
3. **Delayed returns:** Benefits are not immediate, as nutrient release depends on decomposition.
4. **Knowledge gaps:** Limited awareness and training on green manure practices hinder adoption.
5. **Lack of market incentives:** There are no direct market returns from green manure crops, which discourages farmers.
6. **Inadequate policy support:** Insufficient inclusion in subsidy schemes and extension services.

Strategies for Promotion and Adoption

To enhance the adoption of green manuring, the following measures are recommended:

1. **Awareness campaigns and training programs** for farmers on benefits and practices.
2. **Subsidies or incentives** for growing and incorporating green manure crops.
3. **Research and development** to identify region-specific crops and practices.
4. **Integration with government schemes** like soil health cards and organic farming missions.
5. **Mechanization support** for sowing, harvesting, and incorporation of green manure crops.
6. **Inclusion in curriculum and farmer field schools** to spread knowledge.
7. **Demonstration plots and model farms** to show real-time benefits.

Future Perspectives and Research Needs

Future research should focus on:

1. Developing high-biomass, fast-growing green manure varieties.
2. Understanding the interaction of green manures with soil microbiomes.
3. Studying the impact of green manuring under climate change scenarios.
4. Exploring green manuring in conservation agriculture and no-till systems.
5. Economic modeling to demonstrate long-term benefits.
6. Standardizing best practices for diverse agroecological zones.
7. Integrating digital advisory tools to guide farmers on crop selection and timing.

Collaboration between research institutions, policy makers, and farmer organizations is crucial to mainstream green manuring into sustainable agricultural practices.

Conclusion

Green manuring is a sustainable, low-cost practice with significant potential to enhance

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soil fertility, improve crop productivity and conserve environmental quality. By enriching the soil with organic matter and biologically fixed nitrogen, it reduces dependence on chemical inputs and promotes resilient farming systems. Although challenges related to adoption exist, proactive strategies involving research, extension and policy support can facilitate wider implementation. Embracing green manuring is a vital step toward sustainable soil management and long-term agricultural sustainability. With its role in restoring degraded soils, enhancing biodiversity and supporting climate-smart agriculture, green manuring deserves a prominent place in future farming strategies.

References

Iderawumi, A. M., & Kamal, T. O. (2022). Green manure for agricultural sustainability and improvement of soil fertility. *Farming and Management*, *7*(1), 1-8.

Vakeesan, A., Nishanthan, T., & Mikunthan, G. (2008). Green manures: nature's gift to improve soil fertility. *LEISA-LEUSDEN-*, *24*(2), 16.

Fageria, N. K. (2007). Green manuring in crop production. *Journal of plant nutrition*, *30*(5), 691-719.

Coelho, F. C., Prins, C. L., da Rocha, J. G. D. G., de Jesus, V. P., Teixeira, N. S., Eiras, P. P., & Vaz, A. S. (2024). Advancing agricultural sustainability in tropical climates: Harnessing the potential of green manuring.

Palchikov, Y. V., Bobrovich, L. V., Volkov, S. A., & Butenko, A. I. (2018). The role of green manure in improving soil fertility. *International Journal of Mechanical Engineering and Technology*, *9*(12), 1347-1353.

Kumar, S., Samiksha, & Sukul, P. (2020). Green manuring and its role in soil health management. *Soil health*, 219-241.

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Drip and Sprinkler Irrigation in Enhancing Water Use Efficiency

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Introduction

Water scarcity is a pressing issue in global agriculture, particularly in arid and semi-arid regions. With increasing population pressure and climate change impacts, efficient water management has become essential for sustainable agricultural productivity. Traditional surface irrigation methods are often inefficient, leading to significant water loss through evaporation, runoff and deep percolation. In this context, micro-irrigation systems such as drip and sprinkler irrigation have emerged as transformative technologies. These systems not only minimize water losses but also enhance water use efficiency (WUE), nutrient delivery and crop yields. This paper explores the principles, advantages, applications and future prospects of drip and sprinkler irrigation in enhancing WUE.

Concept and Principles of Micro-Irrigation

Micro-irrigation refers to the precise and localized application of water directly to the root zone of plants in controlled quantities. Drip and sprinkler irrigation systems are two prominent forms of micro-irrigation:

- **Drip Irrigation:** Delivers water directly to the plant root zone through a network of valves, pipes and emitters.
- **Sprinkler Irrigation:** Simulates rainfall by spraying water through nozzles using pressurized systems.

Both systems aim to maximize water use efficiency by reducing evaporation, deep percolation and runoff.

Drip Irrigation: System Design and Functioning

Drip irrigation consists of the following components:

- Mainline and sub-main pipes
- Laterals with emitters
- Filters and pressure regulators
- Fertilizer injectors

Water is delivered slowly and uniformly to the plant root zone, ensuring optimal moisture availability without waterlogging. This system is ideal for row crops, orchards, vegetables and greenhouse cultivation.

Key advantages include:

- Up to 90% water use efficiency
- Minimal weed growth due to localized watering
- Efficient nutrient delivery through fertigation
- Suitability for varied soil types and terrains

Sprinkler Irrigation: System Overview and Applications

Sprinkler systems distribute water over the crop canopy in the form of droplets, resembling natural rainfall. Components include:

- Pumping unit
- Main and lateral pipes
- Sprinkler heads or nozzles

Sprinkler systems are suitable for cereals, pulses, lawns, and pastures. They are effective for irrigating undulating terrains and sandy soils where water percolation is rapid.

Benefits include:

- Uniform water application
- Reduction in soil erosion and crusting
- Flexibility in water management
- Improved microclimate for crop growth

Water Use Efficiency: Definition and Importance

Water Use Efficiency (WUE) is defined as the ratio of crop yield to the amount of water used.

Figure 1: Drip Irrigation and Sprinkler Irrigation

It is a critical indicator of sustainable water management. Enhancing WUE contributes to:

- Higher crop productivity per unit of water
- Conservation of water resources
- Reduction in production costs
- Enhanced resilience to drought and climate variability

Micro-irrigation systems have demonstrated significant improvements in WUE, ranging from 30% to 70% over conventional methods.

Comparative Analysis of Drip and Sprinkler Systems

Parameter	Drip Irrigation	Sprinkler Irrigation
Application method	Direct to root zone	Overhead spray
Water use efficiency	85-95%	70-85%
Crop suitability	Row crops, orchards	Cereals, lawns, pastures
Energy requirement	Moderate	High
Weed control	Effective	Less effective
Initial cost	High	Moderate

Impact on Crop Yield and Productivity

Numerous field studies have shown that drip and sprinkler irrigation significantly enhance crop yields. Examples include:

- **Tomato:** 30-40% yield increase under drip
- **Wheat and maize:** 20-30% yield increase under sprinkler
- **Fruit crops (grape, pomegranate):** Improved fruit size and quality

These improvements are attributed to optimized water availability, reduced plant stress and improved nutrient uptake.

Role in Soil Moisture Conservation and Nutrient Management

Micro-irrigation minimizes water loss through evaporation and deep percolation. In drip systems, water is applied at low rates, ensuring maximum infiltration and minimal runoff. This leads to:

- Consistent soil moisture in the root zone
- Reduced waterlogging and salinity issues
- Enhanced fertilizer use efficiency through fertigation

Fertigation allows for precise application of nutrients along with irrigation water, reducing wastage and environmental contamination.

Energy and Resource Use Optimization

Drip and sprinkler systems, when coupled with renewable energy sources like solar pumps, offer energy-efficient irrigation solutions. These systems require less water and energy compared to flood irrigation, making them suitable for resource-scarce regions.

Efficient irrigation also reduces labor costs and fuel consumption, contributing to sustainable agricultural intensification.

Adoption in Different Agro-Climatic Zones and Cropping Systems

Micro-irrigation is adaptable to diverse climates and crops:

- **Arid zones:** Essential for water conservation and efficient farming
- **Hilly regions:** Effective in minimizing soil erosion and water runoff

- **Greenhouses:** Drip irrigation ensures precise control of moisture and nutrients

Government schemes like PMKSY (India) and USDA micro-irrigation programs (USA) promote its adoption through subsidies and training.

Economic Feasibility and Farmer Adoption Challenges

Despite long-term economic benefits, initial investment and maintenance costs can be barriers to adoption. Challenges include:

- High installation costs for smallholders
- Need for technical knowledge and training
- Maintenance of filters and emitters

However, cost-benefit analysis shows that returns on investment can be achieved within 2-3 seasons due to yield improvements and input savings.

Environmental Benefits and Sustainability

Drip and sprinkler irrigation contribute to environmental sustainability by:

- Reducing over-extraction of groundwater
- Lowering greenhouse gas emissions from pumps
- Preventing soil erosion and salinization
- Promoting biodiversity through optimized water distribution

These systems align with sustainable development goals (SDGs) on water conservation, food security, and climate resilience.

Limitations and Practical Constraints

Micro-irrigation is not without limitations:

- Clogging of emitters due to poor water quality
- Vulnerability to mechanical damage
- Inadequate extension support in rural areas
- Limited access to credit for marginal farmers

Addressing these requires capacity building, policy support and localized technology solutions.

Future Prospects and Technological Advancements

Emerging innovations in micro-irrigation include:

- Smart irrigation systems with IoT and sensors
- AI-based irrigation scheduling
- Integration with solar energy and remote monitoring
- Use of biodegradable pipes and eco-friendly materials

These advancements promise greater efficiency, adaptability and environmental compatibility.

Conclusion

Drip and sprinkler irrigation systems offer promising solutions to enhance water use efficiency, improve crop productivity and promote sustainable agriculture. Their ability to conserve water, optimize inputs and adapt to various farming conditions makes them crucial tools in addressing water scarcity and climate challenges. While challenges exist in terms of adoption and maintenance, continued research, policy support and farmer education can accelerate the widespread use of these technologies. Investing in micro-irrigation is not only a strategy for enhancing agricultural output but also a step toward achieving long-term food and water security.

References

Fan, J., Lu, X., Gu, S., & Guo, X. (2020). Improving nutrient and water use efficiencies using water-drip irrigation and fertilization technology in Northeast China. *Agricultural Water Management*, *241*, 106352.

Darko, R. O., Shouqi, Y., Junping, L., Haofang, Y., & Xingye, Z. (2017). Overview of advances in improving uniformity and water use efficiency of sprinkler irrigation. *International Journal of Agricultural and Biological Engineering*, *10*(2), 1-15.

Martínez, J., & Reca, J. (2014). Water use efficiency of surface drip irrigation versus an alternative subsurface drip irrigation method. *Journal of Irrigation and Drainage Engineering*, *140*(10), 04014030.

Gameh, M., Abdalla, M., & Aboul-Nasr, M. H. (2000). IMPROVING WATER USE EFFICIENCY USING DRIP AND SPRINKLER IRRIGATION TO GROW

POTATOES AT TWO LOCATIONS IN THE NEW VALLEY. *Journal of Soil Sciences and Agricultural Engineering*, *25*(1), 541-554.

Yao, C., Li, J., Zhang, Z., Liu, Y., Wang, Z., Sun, Z., & Zhang, Y. (2023). Improving wheat yield, quality and resource utilization efficiency through nitrogen management based on micro-sprinkler irrigation. *Agricultural Water Management*, *282*, 108277.

Yang, P., Wu, L., Cheng, M., Fan, J., Li, S., Wang, H., & Qian, L. (2023). Review on drip irrigation: impact on crop yield, quality and water productivity in China. *Water*, *15*(9), 1733.

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Nanobiochar: A Smart Carrier for Nutrient Delivery and Enhanced Fertilizer Efficiency

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Introduction

In the quest for sustainable agriculture, enhancing nutrient use efficiency (NUE) has become a cornerstone of modern farming practices. The prevalent use of chemical fertilizers has undeniably contributed to increased crop productivity, but it has also brought with it a slew of environmental and economic challenges. A significant proportion of the nutrients applied through conventional fertilizers are lost due to leaching, volatilization and surface runoff. This not only reduces NUE but also results in environmental degradation and heightened production costs for farmers.

To mitigate these issues, there is a growing interest in the development of innovative nutrient delivery systems that can better synchronize nutrient availability with plant uptake. Among these, nanotechnology has emerged as a promising frontier. Specifically, nanobiochar, a nano-engineered form of biochar, has attracted attention due to its unique physicochemical properties. These include a high surface area, increased porosity and the presence of reactive functional groups that make it an ideal candidate for controlled and efficient nutrient delivery. This paper explores the concept, mechanisms, benefits, challenges and future potential of using nanobiochar to improve fertilizer efficiency and support sustainable agriculture.

Concept and Properties of Nanobiochar

Nanobiochar is synthesized by reducing conventional biochar to nanoparticles, generally below 100 nanometers in size. This can be achieved using methods such as ball milling, ultrasonication, or hydrothermal treatment. The nano-sizing of biochar significantly enhances its functional attributes, including:

- **High surface area and porosity**: Facilitates superior adsorption and retention of nutrients.
- **Abundant surface functional groups**: Enables effective chemical bonding with nutrient molecules and soil particles.
- **Colloidal stability**: Enhances mobility in the soil and better interaction with plant roots.

These characteristics collectively enable nanobiochar to function as an efficient smart carrier for nutrients. The minute particle size also aids in better integration into the soil microenvironment, thereby improving root-soil-nutrient interactions.

Mechanism of Nutrient Loading and Release

Nanobiochar's ability to load and release nutrients in a controlled manner stems from several key mechanisms:

- **Surface adsorption**: Nutrients are adsorbed onto the surface of nanobiochar through van der Waals forces, hydrogen bonding and electrostatic interactions.
- **Ion exchange**: Functional groups like -COOH and -OH participate in ion exchange processes with nutrient ions such as NH_4^+, K^+ and Ca^{2+}.
- **Encapsulation**: Nutrients may be physically trapped within the porous structure or chemically bonded to form stable, slow-release complexes.

Once applied to the soil, environmental factors such as moisture content, pH levels and microbial activity influence the release of nutrients. This controlled release pattern ensures synchronization with plant nutrient demands, significantly reducing the risks of nutrient fixation and loss.

Impact on Fertilizer Use Efficiency

The integration of nanobiochar into fertilization strategies has been shown to substantially improve NUE. The specific benefits include:

- **Minimized nutrient losses**: Nutrients remain available in the rhizosphere for a longer duration, reducing losses via leaching and volatilization.
- **Sustained nutrient release**: Ensures a continuous supply of nutrients during the crop's growth cycle.
- **Enhanced nutrient uptake**: Nanoparticles can more easily penetrate root zones, improving nutrient absorption efficiency.
- **Reduced fertilizer applications**: Due to its controlled release properties, nanobiochar reduces the frequency and quantity of fertilizer application.

Field trials and laboratory studies report a 20–40% increase in NUE with the use of nanobiochar-based fertilizers, translating into higher crop yields with lower input costs.

Soil Health and Microbial Interactions

Nanobiochar contributes to overall soil health and fosters beneficial interactions within the soil microbiome:

- **Improved soil structure**: Enhances aggregation, porosity and water retention.
- **Microbial habitat**: Provides a conducive environment for beneficial microbes such as nitrogen-fixing bacteria and phosphate-solubilizing fungi.
- **pH buffering**: Neutralizes acidic soils, creating favorable conditions for microbial and plant activity.

Furthermore, nanobiochar can immobilize toxic elements and organic pollutants, thereby safeguarding soil biota. The resultant improved microbial activity boosts nutrient cycling and plant health, reinforcing soil fertility over the long term.

Applications in Different Cropping Systems

The efficacy of nanobiochar has been validated across various cropping systems:

- **Cereal crops**: In crops like rice and maize, nanobiochar has improved nitrogen uptake and grain yields while mitigating ammonia volatilization.
- **Leguminous crops**: Enhances root nodulation and symbiotic nitrogen fixation in crops such as soybeans and chickpeas.
- **Horticultural crops**: Increases nutrient retention and plant vigor in high-value vegetables like tomatoes, bell peppers and leafy greens.

Integrated nutrient management approaches that combine nanobiochar with both organic and inorganic fertilizers have yielded superior results in terms of productivity, soil fertility, and ecological sustainability.

Environmental and Economic Benefits

Nanobiochar-based fertilizers provide several environmental and economic advantages:

- **Environmental benefits**:
  - Reduced nutrient leaching and water body contamination.
  - Lower greenhouse gas emissions associated with fertilizer application.
  - Enhanced soil carbon sequestration contributing to climate change mitigation.
- **Economic benefits:**
  - Decreased fertilizer input requirements, lowering overall costs.
  - Higher and more consistent crop yields and quality.
  - Reduced costs associated with environmental remediation.

These outcomes support global efforts to achieve the United Nations Sustainable Development Goals (SDGs), particularly those related to food security, climate action and sustainable land use.

Challenges and Safety Concerns

Despite its promise, nanobiochar poses certain challenges and risks:

- **Toxicity concerns**: Over-application or improper use may negatively affect soil microbial diversity and function.
- **Lack of regulatory framework**: There are currently no standardized guidelines governing the production, application, or

environmental impact assessment of nanobiochar.
- **Public apprehension**: Misinformation or limited awareness about nanotechnology in agriculture could hinder adoption.
- **Technical limitations**: Challenges include achieving uniform particle size, scalability of production and cost-effectiveness of nano-formulations.

Addressing these issues will require collaborative efforts in research, policy-making and stakeholder education to ensure safe and effective use.

Research Gaps and Future Directions

To harness the full potential of nanobiochar, future research and development should focus on the following areas:

1. **Development of smart formulations**: Combining nanobiochar with micronutrients, bioinoculants, or plant growth regulators to create multifunctional fertilizers.
2. **Integration with precision agriculture**: Utilizing drones, AI and sensor-based technologies for site-specific application and monitoring.
3. **Eco-friendly synthesis methods**: Emphasizing green chemistry approaches that minimize environmental impact during production.
4. **Long-term ecological studies**: Assessing cumulative effects on soil, plant health and ecosystem function across different agroecological zones.
5. **Life cycle and cost-benefit analysis**: Evaluating the economic viability and sustainability of nanobiochar from production to field application.

These research directions will be pivotal in scaling up nanobiochar technologies and integrating them into mainstream agricultural practices.

Application of Nanobiochar in Agriculture

Nanobiochar, a nano-engineered derivative of biochar, is emerging as a smart solution for sustainable agriculture. Its high surface area, porosity and reactive groups make it an ideal carrier for nutrient delivery. By enhancing nutrient use efficiency, it reduces losses, improves soil health and boosts crop productivity.

Conclusion

Nanobiochar offers a revolutionary advancement in agricultural nutrient management. Its nano-scale characteristics facilitate efficient nutrient adsorption, controlled release and improved plant-soil interactions. These attributes translate into enhanced fertilizer efficiency, better crop yields, improved soil health and minimized environmental degradation.

While challenges such as potential toxicity, regulatory gaps and public skepticism persist, these can be overcome through rigorous scientific validation, inclusive policy frameworks and effective extension services. As agriculture grapples with the twin pressures of increasing food demand and environmental conservation, nanobiochar emerges as a strategic tool for future-ready, climate-smart farming. With continued interdisciplinary collaboration and innovation, nanobiochar can significantly contribute to the global transition toward sustainable agriculture and food systems.

References

Chakraborty, R., Mukhopadhyay, A., Paul, S., Sarkar, S., & Mukhopadhyay, R. (2023). Nanocomposite-based smart fertilizers: A boon to agricultural and environmental sustainability. *Science of the Total Environment*, *863*, 160859.

Deb, P. (2025). Enhancing the Nutrient Use Efficiency Through Nano-Biochar. In *Nanomaterials and Nano-Biochar in Reducing Soil Stress* (pp. 115-136). Apple Academic Press.

Ramanayaka, S., Vithanage, M., Alessi, D. S., Liu, W. J., Jayasundera, A. C., & Ok, Y. S. (2020). Nanobiochar: production, properties, and multifunctional applications. *Environmental Science: Nano*, *7*(11), 3279-3302.

Kyebogola, S., Kabiri, S., Onwonga, R. N., Semalulu, O., Yost, R., & Sseruwu, G. (2024).

A Review of Potential on Possible Greener Production of Slow-Release Nitrogen Fertilizer: From Fundamentals of Plasma and Nanotechnology Application.

Rasool, A., Krismastuti, F. S. H., Zulfajri, M., Meliana, Y., & Sudewi, S. (2024). A smart way to increase the growth and productivity of crops through nano-fertilizer. In *Molecular impacts of nanoparticles on plants and algae* (pp. 333-346). Academic Press.

Sani, M. N. H., Amin, M., Siddique, A. B., Nasif, S. O., Ghaley, B. B., Ge, L., ... & Yong, J. W. H. (2023). Waste-derived nanobiochar: a new avenue towards sustainable agriculture, environment, and circular bioeconomy. *Science of the Total Environment*, *905*, 166881.

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AI-Driven Drones in Horticulture: Revolutionizing Precision Farming

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Introduction

The agricultural landscape is undergoing a transformative shift driven by technological innovations aimed at increasing productivity, sustainability and resource efficiency. Among these technologies, Artificial Intelligence (AI) and drone-based solutions have emerged as powerful tools in modern horticulture. Horticultural crops, known for their sensitivity to microclimatic and management conditions, demand timely interventions and precision practices for optimal growth and yield. AI-powered drones combine advanced imaging, data analytics and automation to enable site-specific management, reduce input wastage and enhance crop monitoring in real time. This paper explores the applications, benefits, challenges and future prospects of integrating AI-enabled drones into horticultural farming systems.

Role of Drones in Horticulture

Drones, also known as Unmanned Aerial Vehicles (UAVs), offer several functional capabilities in horticulture:

1. **Aerial Imaging and Mapping**: High-resolution imagery allows monitoring of crop health, identifying stress areas and detecting pest infestations.
2. **Precision Spraying**: Targeted spraying of pesticides and fertilizers minimizes wastage and environmental contamination.
3. **Soil and Crop Monitoring**: Multispectral and thermal sensors provide data on soil moisture, canopy temperature and plant vigour.
4. **Growth Stage Monitoring**: Time-lapse data from drones can assess phenological changes and guide harvesting decisions.
5. **Surveillance**: Monitoring large orchards or greenhouse facilities for theft, damage, or animal intrusions.

Integration of Artificial Intelligence

The inclusion of AI in drone technology significantly enhances its decision-making capacity. Key AI functions include:

1. **Image Recognition and Classification**: AI algorithms identify diseases, nutrient deficiencies, or weed infestations through pattern analysis in aerial images.
2. **Predictive Analytics**: Based on historical and real-time data, AI models predict crop yield, growth rates and outbreak risks.
3. **Autonomous Navigation**: AI enables drones to map fields, avoid obstacles and fly predefined paths with minimal human input.
4. **Real-Time Alerts**: AI systems can issue instant alerts to farmers about crop anomalies detected through drone footage.
5. **Data Integration**: Machine learning models combine drone data with weather forecasts, soil data and market trends to guide agronomic decisions.

Applications in Fruit Science

AI drones offer specific advantages in fruit crops:

1. **Canopy Mapping in Orchards**: Helps manage pruning, pest spraying and irrigation in dense orchards such as mango, apple and citrus.
2. **Blossom Counting and Fruit Sizing**: AI models analyze bloom intensity and estimate fruit load, aiding in thinning and harvest planning.
3. **Pest and Disease Detection**: Early signs of fungal infections or insect attacks in fruits

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like grapes and pomegranates can be identified.

4. **Pollination Monitoring**: Drone-based surveillance can track pollinator activity and flower health in fruit crops reliant on cross-pollination.

Applications in Vegetable Science

Vegetables, due to their shorter growth cycles, benefit immensely from rapid, precise interventions:

1. **Plant Population Assessment**: Drones count plant stands post-germination to assess establishment rates.
2. **Weed Identification**: AI algorithms distinguish between crop and weed species, allowing for site-specific herbicide application.
3. **Fertility Mapping**: Drones equipped with spectral sensors can monitor nutrient deficiencies and help in variable-rate fertilizer application.
4. **Disease Spotting**: Spotting viral or bacterial infections in leafy vegetables like spinach and cabbage aids in containment and management.

Applications in Floriculture

The ornamental plant industry benefits from AI drones in:

1. **Color and Bloom Analysis**: Drones monitor bloom cycles and color intensity, aiding in quality grading and market scheduling.
2. **Greenhouse Monitoring**: Indoor drones check environmental conditions like humidity and temperature variations in polyhouses.
3. **Inventory Management**: AI-powered mapping of floriculture farms assists in real-time inventory tracking and yield forecasting.
4. **Aesthetic Quality Control**: Image analysis ensures uniformity in flower size, symmetry, and health for premium floriculture markets.

Enhancing Resource Use Efficiency

AI drones directly contribute to efficient resource utilization:

- **Water Use Efficiency**: Soil moisture maps created by drones allow precision irrigation, preventing both under- and over-watering.
- **Pesticide Efficiency**: Drones apply chemicals only where needed, reducing pesticide usage by 30–50%.
- **Fertilizer Efficiency**: Site-specific application of nutrients minimizes leaching and boosts nutrient use efficiency (NUE).
- **Labour Optimization**: Automating repetitive tasks reduces dependency on manual labor and enhances timeliness of operations.

Environmental and Economic Benefits

Environmental Benefits:

- Lower pesticide and fertilizer runoff reduces soil and water contamination.
- Reduced carbon footprint due to optimal input usage.
- Enhances biodiversity by minimizing chemical overuse.

Economic Benefits:

- Reduction in operational costs (labour, chemicals, water).
- Higher yields and quality grades fetch better market prices.
- Improved decision-making reduces crop loss risks and enhances return on investment (ROI).

Challenges in Implementation

Despite its promise, AI drone adoption in horticulture faces several constraints:

1. **High Initial Investment**: Cost of drones and AI software is a barrier for smallholders.
2. **Technical Skills Requirement**: Farmers require training to interpret drone data and operate AI tools effectively.
3. **Connectivity and Data Management**: Rural areas often lack reliable internet or cloud infrastructure.

4. **Regulatory Hurdles**: Airspace permissions, data privacy and drone licensing are often complicated.
5. **Battery Limitations**: Short flight time limits surveillance of large farms.

Case Studies

1. **Apple Orchards in Himachal Pradesh:** Drones are used for mapping slopes, monitoring flower bloom stages and spotting early signs of scab disease.
2. **Tomato Fields in Maharashtra:** AI-enabled drones helped detect early-stage leaf curl virus, allowing for targeted sprays and minimizing crop loss.
3. **Rose Polyhouses in Bengaluru:** Drones have enabled monitoring of temperature gradients and uniformity in bloom, improving grading and exports.

Future Prospects and Innovations

- **Swarm Drones**: Multiple drones working collaboratively can manage larger farms simultaneously.
- **AI-IoT Integration**: Combining drones with soil and weather sensors for real-time adaptive management.
- **Drone-as-a-Service (DaaS)**: Business models where service providers rent drones to farmers for a fee.
- **Autonomous Pollen Drones**: AI drones mimicking insect pollination in greenhouse crops.
- **Blockchain Integration**: Linking drone-collected data with traceability platforms to ensure quality assurance.

Policy and Institutional Support

- **Subsidies and Incentives**: Government support for purchasing drones, especially for FPOs and SHGs.
- **Skill Development**: Training programs under schemes like PM-Kisan and Skill India for drone pilots and AI technicians.
- **Research Funding**: Grants for developing affordable AI-drones suited to Indian farm conditions.
- **Custom Hiring Centres (CHCs)**: Equipping CHCs with AI drones to make technology accessible to smallholders.

Conclusion

AI-powered drones represent a paradigm shift in the management of horticultural crops, offering unparalleled precision, speed and efficiency. From disease detection and resource optimization to yield forecasting and pollination support, their utility spans the entire horticultural value chain. Despite infrastructural and regulatory hurdles, the integration of AI and drone technologies promises to address many of the existing inefficiencies in horticulture. With targeted investments, capacity building and inclusive policies, AI drones can empower horticulture to meet the growing challenges of climate change, resource scarcity and food demand in the 21st century.

References

Ghosh, D., Siddique, M. A., & Pal, D. (2024). AI-Driven Precision Agriculture Approach. *AI in Agriculture for Sustainable and Economic Management*, *6*, 67.

Singh, H. P., & Parihar, J. S. (2024). Paradigms in digital horticulture: A prospective. *International Journal of Innovative Horticulture*, *13*(2), 105-123.

Siddharth, K., Shristi, T. K. P., & Isaac, R. K. Enhancing Sustainable Agriculture and Horticulture through Smart Technologies: A Study on the Integration of IoT, AI, and Precision Farming Tools.

Sharma, A., Chahal, A. S., Singh, K. K., & Pathania, R. AI and Drone Technologies in Agriculture.

Singh, B., Sharma, H., & Sharma, M. M. (2025). Application of AI in Hi-Tech Horticulture. *Smart Agriculture: Merging Innovation, Efficiency and Sustainability: Artificial Intelligence, Smart Farming, Sustainable Agriculture, Internet of Things*, 97.

Gammanpila, H. W., Sashika, M. N., & Priyadarshani, S. V. G. N. (2024). Advancing Horticultural Crop Loss Reduction Through Robotic and AI Technologies: Innovations, Applications, and Practical Implications. *Advances in Agriculture*, *2024*(1), 2472111.

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Impacts of Climate Change on Horticultural Crops: Challenges, Adaptation Strategies and Sustainable Futures

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Introduction

Climate change has emerged as one of the most significant challenges to agriculture worldwide, particularly affecting horticultural crops due to their high sensitivity to environmental conditions. Changes in temperature, rainfall patterns, extreme weather events and increased levels of greenhouse gases have profound implications for the productivity, quality and distribution of fruits, vegetables and ornamental plants. Horticulture not only contributes significantly to agricultural GDP and nutrition but also offers livelihood to millions of smallholders. Thus, the sector's vulnerability to climate change presents a dual challenge: ensuring food security and sustaining farm incomes. This paper outlines the various ways in which climate change influences horticultural crop systems and discusses potential adaptation and mitigation strategies to safeguard future production.

Climate Change: Key Factors Affecting Horticulture

1. **Temperature Rise**
   - Alters phenology, flowering and fruiting time.
   - Increases respiration rate leading to reduced yield.
   - Heat stress may lead to flower drop and fruit damage.
   - Delays or hastens maturity, impacting market timing.
2. **Altered Precipitation Patterns**
   - Increased rainfall can cause waterlogging, root diseases.
   - Drought affects crop growth, flowering, and water-use efficiency.
   - Erratic rains interfere with irrigation planning and harvesting.
3. **Elevated CO_2 Levels**
   - Can stimulate photosynthesis and growth.
   - May improve yield in some crops but reduce nutritional quality.
   - Altered carbon-nitrogen balance may affect plant physiology.
4. **Extreme Weather Events**
   - Cyclones, frost, hailstorms and floods can destroy crops.
   - Damage infrastructure and affect harvest and marketability.
   - Affect logistics and cold chain operations.
5. **Pest and Disease Incidence**
   - Rising temperatures expand pest habitat ranges.
   - New pests and diseases emerge or intensify.
   - Existing biocontrol systems may become ineffective.

Direct Impacts of Climate Change on Horticultural Crops

1. **Physiological Effects**

- **Altered Growth and Development**: High temperatures may shorten growth cycles, reducing yield potential.
- **Changes in Flowering and Fruiting Patterns**: Erratic weather disrupts pollination, affecting fruit crops like apples and cherries.
- **Water Stress and Drought Sensitivity**: Crops like grapes and citrus suffer from water scarcity, leading to smaller fruits and lower juice quality.

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2. **Impact on Yield and Quality**

- **Reduced Yields:** Due to heat stress, drought and erratic rainfall, limiting photosynthesis and nutrient uptake.
- **Quality Deterioration:** Affects taste, texture, shelf life and visual appeal (color, size, shape).
- **Pollination Issues:** Heat affects pollinators like bees, reducing fruit set and quality.
- **Nutritional Changes:** Elevated CO_2 reduces protein, vitamin C and micronutrient levels in vegetables and fruits.
- **Post-Harvest Losses:** Increased respiration and faster spoilage due to higher temperatures.

Indirect Impacts on Horticultural Systems

1. **Soil Health and Nutrient Availability:** Climate change alters soil microbial activity, reducing nutrient cycling. Droughts and floods degrade soil structure, affecting root development.
2. **Pollinator Decline and Reproductive Success:** Bees and other pollinators are sensitive to temperature changes, leading to poor fruit set in crops like almonds and blueberries.
3. **Shifts in Suitable Growing Regions:** Traditional growing zones may become unsuitable, forcing farmers to shift locations or adopt new crop varieties.
4. **Economic Consequences for Farmers:** Lower yields and higher input costs (e.g., irrigation, pest control) reduce profitability, particularly for small-scale farmers.

Crop-Specific Impacts

a. Fruit Crops:

- **Mango:** Flowering is highly temperature-sensitive; irregular flowering and reduced fruit set under high temperature.
- **Apple:** Requires chilling hours; warming reduces suitable areas for cultivation and leads to poor fruit quality.
- **Banana:** Susceptible to high winds and temperature stress; water scarcity affects yield.
- **Grapes**: High temperature affects sugar accumulation and berry quality; unseasonal rains may damage ripening clusters.

b. Vegetable Crops:

- **Tomato**: Heat stress leads to reduced fruit set, fruit cracking and sunscald.
- **Onion and Garlic**: Bulb development sensitive to moisture and temperature; poor storability under high humidity.
- **Brinjal and Chilli**: Affected by heat, increased pest load and blossom drop.

c. Floricultural Crops:

- **Roses and Marigold:** Altered flowering time, reduced flower size and shorter vase life.
- **Chrysanthemums and Orchids:** Temperature fluctuations disrupt flowering cycle, affect pigmentation and scent quality.

Socio-Economic Implications

- **Increased Production Costs:** Due to higher irrigation, pest control, nutrient inputs and climate-proofing investments.
- **Market Volatility:** Yield and quality fluctuations affect prices, market arrivals and farmer income.
- **Livelihood Risk:** Small and marginal farmers lack coping capacity for recurring climate shocks.
- **Labour Shortages:** Climate extremes deter seasonal labour availability and increase cost of operations.
- **Food and Nutritional Security:** Decreased supply of perishable horticultural products affects dietary diversity.

Adaptation Strategies

1. **Crop Diversification**
   - Cultivating multiple species to spread risk and ensure income.
   - Inclusion of indigenous, drought-tolerant and underutilized species.
2. **Improved Varieties**
   - Development and adoption of heat, drought, flood and pest-resistant cultivars.

- Use of rootstocks that are tolerant to abiotic stress.

3. **Efficient Water Management**
   - Use of drip and sprinkler irrigation to improve water-use efficiency.
   - Water harvesting, check dams and mulching to conserve soil moisture.
4. **Protected Cultivation**
   - Use of greenhouses, shade nets, polyhouses and low tunnels.
   - Ensures off-season production and quality control.
5. **Climate-Smart Practices**
   - Adjusting sowing/planting dates based on weather forecasts.
   - Precision agriculture using remote sensing and soil health monitoring.
   - Use of organic mulches and conservation tillage.
6. **Integrated Pest and Disease Management (IPDM)**
   - Monitoring and forecasting pest outbreaks.
   - Use of resistant varieties, biological control and neem-based pesticides.
7. **Use of ICT Tools**
   - Mobile apps, automated weather stations and early warning systems.
   - Customized advisories for farmers based on location and crop stage.
8. **Post-Harvest Infrastructure**
   - Climate-resilient cold storage and transport systems.
   - Minimizing post-harvest losses and ensuring marketability.

Policy and Institutional Support

- **Climate-Resilient Agriculture Programs:** Inclusion of horticulture in national climate action plans.
- **Subsidies and Insurance:** Support for protected cultivation, weather-indexed insurance.
- **Research and Development:** Strengthening regional centers for stress-tolerant crop research.
- **Training and Capacity Building:** Farmer field schools, climate literacy workshops.
- **Public-Private Partnerships:** Enhancing access to technology, finance and value chains.
- **Infrastructure Development:** Investment in climate-proofing markets, roads and irrigation systems.

Future Research Needs

- Mapping vulnerability zones for horticultural crops under different climate scenarios.
- Developing region-specific adaptive crop calendars and production packages.
- Modeling impacts of long-term climate change on productivity and quality.
- Economic analysis of climate-resilient practices.
- Screening and promoting traditional and wild relatives for climate tolerance.
- Exploring plant-microbe interactions for stress resilience.
- Application of AI and big data in climate-smart horticulture.

Conclusion

Horticultural crops, being highly climate-sensitive, are at significant risk from ongoing climatic changes. These impacts not only threaten yield and quality but also disrupt market dynamics and farmer livelihoods. Proactive adaptation, supported by technology, research and policy measures, is essential to mitigate adverse effects. A holistic approach involving climate-resilient varieties, efficient resource use and institutional support can ensure the sustainability and profitability of horticultural production systems in a changing climate. Investing in resilient horticulture today will safeguard food security, nutrition and farmer well-being in the future. In this context, convergence between stakeholders' farmers, scientists, extension agencies and policymakers is key to building a climate-resilient horticultural sector.

References

Malhotra, S. K. (2017). Horticultural crops and climate change: A review. *The Indian Journal of Agricultural Sciences*, *87*(1), 12-22.

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Saqib, M., Anjum, M. A., Ali, M., Ahmad, R., Sohail, M., Zakir, I., ... & Hussain, S. (2022). Horticultural crops as affected by climate change. *Building Climate Resilience in Agriculture: Theory, Practice and Future Perspective*, 95-109.

Rehman, M. U., Rather, G. H., Gull, Y., Mir, M. R., Mir, M. M., Waida, U. I., & Hakeem, K. R. (2015). Effect of climate change on horticultural crops. In *Crop production and global environmental issues* (pp. 211-239). Cham: Springer International Publishing.

Gora, J. S., Verma, A. K., Singh, J., & Choudhary, D. R. (2019). Climate change and production of horticultural crops. In *Agricultural Impacts of Climate Change [Volume 1]* (pp. 45-61). CRC Press.

Datta, S. (2013). Impact of climate change in Indian horticulture-a review. *International Journal of Science, Environment and Technology*, *2*(4), 661-671.

Moretti, C. L., Mattos, L. M., Calbo, A. G., & Sargent, S. A. (2010). Climate changes and potential impacts on postharvest quality of fruit and vegetable crops: A review. *Food Research International*, *43*(7), 1824-1832.

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Use of Biostimulants in Horticultural Crops: Enhancing Growth, Yield and Resilience

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Introduction

The rising demand for sustainable agriculture and the increasing stress from climate change have directed attention toward alternative and eco-friendly agricultural inputs. One such innovation is the use of biostimulants, which play a pivotal role in enhancing plant health, productivity and resistance to abiotic and biotic stressors. Biostimulants are neither fertilizers nor pesticides; they are substances or microorganisms that, when applied to plants or soils, stimulate natural processes to improve nutrient uptake, enhance efficiency and increase crop quality and stress tolerance. In horticulture, where crops are high-value and sensitive to environmental changes, biostimulants can significantly contribute to improving yield and maintaining quality under sub-optimal conditions. This paper elaborates on the types, modes of action, benefits, application techniques and future prospects of biostimulants in horticultural crop production.

Defining Biostimulants

Biostimulants are defined as substances or microorganisms that enhance plant growth and development independently of the nutrient content. Their primary function is to stimulate natural processes in plants that enhance nutrient uptake, efficiency, tolerance to stress and crop quality. They can be derived from natural or synthetic sources and are compatible with both conventional and organic farming systems.

Classification of Biostimulants

Biostimulants are broadly classified into the following categories:

a. Humic and Fulvic Acids:

- Extracted from leonardite or organic compost.
- Improve root development, nutrient uptake and soil microbial activity.

b. Seaweed Extracts:

- Derived mainly from brown algae (Ascophyllum nodosum).
- Promote cell division, flowering and fruit set.

c. Protein Hydrolysates and Amino Acids:

- Contain peptides and amino acids derived from animal or plant sources.
- Stimulate metabolic activity and promote enzyme function.

d. Microbial Biostimulants:

- Include Plant Growth Promoting Rhizobacteria (PGPR) like Azospirillum, Bacillus and mycorrhizal fungi.
- Enhance nutrient solubilization, nitrogen fixation and stress resistance.

e. Chitosan and Other Biopolymers:

- Derived from crustacean shells.
- Activate defense mechanisms and reduce pathogen attacks.

f. Inorganic Compounds:

- Silicon, selenium, and cobalt can function as biostimulants in trace amounts.
- Aid in stress resistance and structural reinforcement.

Mode of Action of Biostimulants in Plants

Biostimulants enhance plant growth and stress resilience through multifaceted biochemical, physiological and molecular mechanisms. Below is a comprehensive breakdown of their actions:

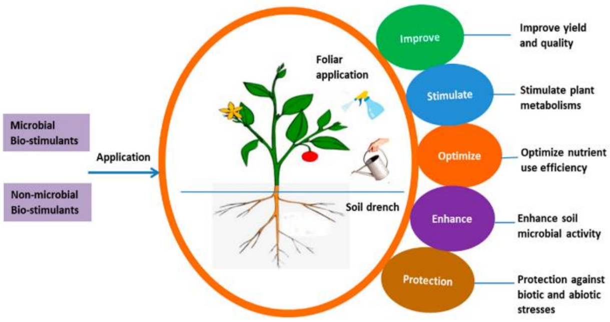

Figure 1: Bio-stimulatory effect on plant growth and productivity

1. Root Development

Mechanism:

- Lateral Root Initiation: Biostimulants (e.g., humic acids, seaweed extracts) upregulate genes like *AUX/IAA* and *ARF*, promoting auxin-mediated lateral root formation.
- Root Hair Proliferation: Microbial biostimulants (e.g., *Trichoderma*) secrete indole-3-acetic acid (IAA), increasing root surface area by 20–40%.

Impact:

- Improves water/nutrient uptake efficiency, especially in drought-prone soils.
- Example: Azospirillum inoculation increases root volume in maize by 35% (Calvo et al., 2014).

2. Photosynthesis Enhancement

Mechanism:

- Chlorophyll Synthesis: Seaweed extracts (e.g., Ascophyllum nodosum) supply betaines and micronutrients (Mg^{2+}, Fe^{2+}) to boost chlorophyll production.
- Light Absorption: Protein hydrolysates improve photosystem II (PSII) efficiency by stabilizing the D1 protein.

Impact:

- Increases net photosynthetic rate by 15–30%.
- Example: Kelp-based biostimulants raised spinach yield by 22% under low light

3. Stress Tolerance

Mechanism:

- **Antioxidant Defense**:
  - Biostimulants activate *SOD* (superoxide dismutase), *CAT* (catalase) and *APX* (ascorbate peroxidase) enzymes to scavenge ROS.
  - Polysaccharides from algae induce systemic acquired resistance (SAR).
  - Osmoprotectant Accumulation: Proline and glycine betaine mitigate osmotic stress.

4. Hormonal Regulation

Mechanism:

- **Auxin-Cytokinin Balance:**
  - Humic substances mimic auxin effects, stimulating cell elongation.
  - Seaweed extracts elevate cytokinins (e.g., zeatin), delaying senescence.
  - Gibberellin Synergy: Microbial biostimulants (e.g., *Bacillus* spp.) produce GA3, enhancing stem elongation.

5. Improved Nutrient Uptake

Mechanism:

- **Solubilization:**
  - Microbial biostimulants secrete siderophores and organic acids (e.g., citric acid) to chelate Fe^{3+}, P and Zn.
- **Assimilation:**
  - Protein hydrolysates provide amino acids (e.g., glutamate) as N carriers.
  - Chitosan nanoparticles enhance membrane permeability for NO_3^- uptake.

Integrated Effects on Crop Performance

Parameter	Improvement (%)	Key Biostimulant
Root Biomass	+20-40	Humic Acids
Photosynthetic Rate	+15-30	Seaweed extracts
Stress Recovery	+40-60	Microbial consortia
Nutrient Use Efficiency	+25-50	Protein hydrolysates

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Benefits in Horticultural Crops

Biostimulants have demonstrated several benefits in the cultivation of fruits, vegetables and ornamental plants:

a. Fruit Crops

- **Mango:** Seaweed extracts and humic acid improve flowering and fruit retention.
- **Grapes:** Enhanced berry size, sweetness (°Brix) and uniform ripening.
- **Apple:** Amino acid-based products improve coloration and shelf-life.
- **Banana:** Improved resistance to drought and uniformity in bunch development.

b. Vegetable Crops

- **Tomato**: Protein hydrolysates promote early flowering and reduce fruit cracking.
- **Onion**: Enhanced bulb size, better storability under humid conditions.
- **Brinjal:** Increased vigor and better resistance to Fusarium wilt with microbial formulations.

c. Ornamental Crops

- **Roses:** Seaweed extracts improve bud development, bloom size and vase life.
- **Marigold and Chrysanthemum:** Amino acids and humic substances encourage more uniform flowering and longer bloom duration.

Application Methods of Biostimulants: Techniques and Optimization Strategies

Biostimulants can be applied through multiple methods, each offering unique advantages depending on the crop type, growth stage and targeted physiological response. Below is an expanded analysis of each application method, including mechanisms, benefits and practical considerations:

1. Seed Treatment

Mechanism:

- Coating seeds with biostimulants (e.g., chitosan, microbial inoculants) primes germination by:
  - Activating hydrolytic enzymes (α-amylase, proteases) to break down seed reserves.
  - Inducing systemic resistance against soil-borne pathogens.

Benefits:

- Uniform germination: Reduces variability in seedling emergence (e.g., 15–20% faster germination in maize).
- Early vigor: Enhances root biomass by 30–50% in crops like soybean and wheat.

2. Foliar Application

Mechanism:

- Biostimulants (e.g., seaweed extracts, amino acids) enter through stomata/cuticle and:
  - Stimulate photosynthetic enzymes (Rubisco) within 24–48 hours.
  - Trigger antioxidant production (e.g., glutathione) under stress.

Benefits:

- Rapid response: Ideal for correcting nutrient deficiencies or abiotic stress (e.g., salinity).
- Efficiency: 60–80% absorption rate for small molecules (e.g., glycine betaine).

3. Soil Drenching

Mechanism:

- Liquid biostimulants (e.g., humic acids, PGPR) modify soil-plant interactions by:
  - Chelating nutrients (Fe^{3+}, Zn^{2+}) in the rhizosphere.
  - Enhancing microbial diversity (e.g., Pseudomonas spp. populations increase 5-fold).

Benefits:

- Long-term effects: Improves soil structure and cation exchange capacity (CEC).
- Root-targeted: Ideal for perennial crops (e.g., vineyards, orchards).

4. Fertigation

Mechanism:

- Biostimulants delivered via irrigation systems:
  - Synchronize with nutrient pulses (e.g., N-P-K) to enhance uptake.
  - Maintain stable microbial viability in drip lines (pH 6.0–7.0).

Benefits:

- Precision: Uniform distribution to root zones, saving 20–30% input costs.
- Scalability: Suitable for large-scale row crops (e.g., corn, potatoes).

5. Root Dipping (Transplants)

Mechanism:

- Dipping seedling roots in biostimulant slurries:
  - Forms protective microbial biofilms (e.g., *Mycorrhizae* on tomato roots).
  - Reduces transplant shock by elevating endogenous ABA.

Benefits:

- Survival rate: Increases transplant success by 50–70% in vegetables (e.g., cabbage, lettuce).
- Early establishment: Roots recover 3–5 days faster post-transplant.

Role in Abiotic Stress Mitigation

Biostimulants are highly effective in helping plants cope with environmental stresses:

- **Drought:** Maintain water status and reduce leaf wilting.
- **Salinity:** Help in ion balance and osmotic regulation.
- **Temperature Extremes:** Reduce chilling and heat injury.
- **Heavy Metal Stress:** Microbial biostimulants can detoxify pollutants and enhance tolerance.

Integration with Farming Systems

Biostimulants can be seamlessly integrated into:

- **Organic Farming:** Approved formulations comply with organic standards.
- **Integrated Nutrient Management (INM):** Work synergistically with chemical fertilizers.
- **Protected Cultivation:** Enhance performance under polyhouse and net house conditions.
- **Precision Farming:** Use in combination with sensors and automated fertigation systems.

Challenges in Adoption

Despite numerous benefits, some constraints limit the widespread adoption of biostimulants:

- **Lack of Standardization:** Variable formulations lead to inconsistent results.
- **Limited Farmer Awareness:** Inadequate extension efforts hinder adoption.
- **High Cost:** Some imported products are not cost-effective for smallholders.
- **Weak Regulatory Framework:** Ambiguity in classification and registration requirements.
- **Short Shelf-Life of Microbial Products:** Storage and transportation challenges.

Conclusion

Biostimulants offer a promising solution for enhancing productivity, quality and sustainability in horticulture. Their ability to improve nutrient efficiency, increase stress tolerance and reduce the dependency on chemical inputs makes them ideal for modern agriculture. Although challenges like standardization, awareness and regulation persist, ongoing research, innovation and policy support can pave the way for their broader adoption. A comprehensive approach involving scientific validation, farmer education and institutional backing is necessary to unlock the full potential of biostimulants in horticultural crop production. As agriculture moves towards climate-resilient and eco-friendly practices, biostimulants are poised to play a crucial role in shaping the future of sustainable horticulture.

References

Sani, M. N. H., & Yong, J. W. (2021). Harnessing synergistic biostimulatory processes: A plausible approach for enhanced crop growth and resilience in organic farming. *Biology*, *11*(1), 41.

Drobek, M., Frąc, M., & Cybulska, J. (2019). Plant biostimulants: Importance of the quality and yield of horticultural crops and the improvement of plant tolerance to abiotic stress—A review. *Agronomy*, *9*(6), 335.

Parađiković, N., Teklić, T., Zeljković, S., Lisjak, M., & Špoljarević, M. (2019). Biostimulants research in some horticultural plant species—A review. *Food and Energy Security*, *8*(2), e00162.

Bulgari, R., Franzoni, G., & Ferrante, A. (2019). Biostimulants application in horticultural crops under abiotic stress conditions. *Agronomy*, *9*(6), 306.

Bell, J. C., Bound, S. A., & Buntain, M. (2022). Biostimulants in agricultural and horticultural production. *Horticultural reviews*, *49*, 35-95.

Sangiorgio, D., Cellini, A., Donati, I., Pastore, C., Onofrietti, C., & Spinelli, F. (2020). Facing climate change: application of microbial biostimulants to mitigate stress in horticultural crops. *Agronomy*, *10*(6), 794.

Ornamental Plants as Natural Air Purifiers: Role in Environmental Health and Urban Sustainability

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Introduction

Urbanization, industrialization and a growing vehicular population have led to an alarming increase in air pollution levels worldwide. This pollution not only affects the environment but also has severe consequences for human health, contributing to respiratory illnesses, cardiovascular diseases and a decline in overall quality of life. As cities strive to become more livable and sustainable, the role of green spaces and vegetation in mitigating pollution has gained increasing attention. Among these, ornamental plants hold unique significance due to their aesthetic appeal, versatility and functional benefits. Beyond beautification, ornamental plants can act as natural air purifiers by absorbing pollutants, capturing particulate matter and improving microclimatic conditions. This paper explores the potential of ornamental plants in purifying the air, highlights their mechanisms of action, reviews suitable plant species and emphasizes their role in environmental health and sustainable urban development.

The Concept of Phytoremediation

Phytoremediation refers to the use of plants to absorb, degrade, or neutralize pollutants from the environment. This includes air, water and soil remediation. In the context of air purification, phytoremediation involves several mechanisms:

- **Absorption of gases** such as carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur dioxide (SO_2) and ozone (O_3) through stomata.
- **Deposition of particulate matter (PM)** on leaves and stems.
- **Volatile Organic Compound (VOC) removal**, including benzene, formaldehyde and toluene.
- **Oxygen release** and **humidity regulation** through transpiration.

Ornamental plants, which are often selected for their foliage, longevity and adaptability, can serve these functions effectively in urban and indoor environments.

Key Mechanisms of Air Purification by Ornamental Plants

1. Absorption of Gaseous Pollutants

Plants absorb gaseous pollutants through their stomata. Ornamental species with broad, waxy leaves or large surface areas are particularly effective at capturing gaseous pollutants such as:

- Carbon monoxide (CO)
- Nitrogen dioxide (NO_2)
- Sulfur dioxide (SO_2)
- Ozone (O_3)
- Volatile Organic Compounds (VOCs)

2. Particulate Matter Deposition

Leaves of ornamental plants trap airborne particulate matter (PM_{10} and $PM_{2.5}$), which are among the most harmful air pollutants. The rough surface texture and dense canopy of many ornamental shrubs and trees help capture dust, soot and smoke particles, thus reducing their concentration in the ambient air.

3. Microclimate Regulation

Ornamental plants influence the urban microclimate by reducing ambient temperatures, increasing humidity and providing shade. This indirectly helps in lowering ground-level ozone and other temperature-sensitive pollutants.

4. Production of Phytoncides

Some ornamental plants release bioactive volatile compounds known as phytoncides, which possess antimicrobial properties. These compounds not only purify the air but also enhance mental well-being.

Selection of Ornamental Plants for Air Purification

1. Indoor Ornamental Plants

Several indoor ornamental plants are proven to remove pollutants effectively. Notable examples include:

- **Areca Palm (*Dypsis lutescens*)** – Removes benzene and formaldehyde.
- **Spider Plant (*Chlorophytum comosum*)** – Effective against carbon monoxide and xylene.
- **Peace Lily (*Spathiphyllum wallisii*)** – Absorbs VOCs and improves humidity.
- **Snake Plant (*Sansevieria trifasciata*)** – Removes toxins like nitrogen oxides and formaldehyde.
- **Aloe Vera** – Absorbs formaldehyde and provides medicinal value.

2. Outdoor Ornamental Plants

Outdoor landscaping with ornamental plants enhances air quality in urban and peri-urban areas. Key species include:

- **Bougainvillea (*Bougainvillea glabra*)** – Dust capturing and tolerant to harsh conditions.
- **Ashoka Tree (*Polyalthia longifolia*)** – Reduces noise and air pollution.
- **Golden Duranta (*Duranta erecta*)** – Popular for hedging and dust filtration.
- **Ficus (*Ficus benjamina*)** – Large canopy and pollutant-absorbing ability.
- **Tecoma (*Tecoma stans*)** – Adaptable and effective in removing suspended particles.

Benefits of Ornamental Plants in Urban Areas

1. Health Benefits

- Reduction in respiratory and cardiovascular ailments due to cleaner air.
- Improvement in mental health and cognitive performance.
- Promotion of well-being through biophilic experiences.

2. Environmental Benefits

- Carbon sequestration and oxygen release.
- Lowering urban heat island effect.
- Enhanced biodiversity and ecological balance.

3. Socio-Economic Benefits

- Increase in property values and real estate appeal.
- Job creation in landscaping, nursery, and maintenance sectors.
- Promotion of eco-tourism and green initiatives.

Role in Urban Sustainability

Urban sustainability hinges on the integration of green infrastructure into city planning. Ornamental plants are integral to this due to their multifunctional role:

1. **In Green Roofs and Vertical Gardens**: Enhance insulation, reduce energy use and act as natural filters.
2. **In Urban Green Corridors and Parks**: Connect biodiversity zones and improve air quality.
3. **In Traffic Islands and Road Medians**: Serve as pollution buffers by absorbing vehicular emissions.
4. **In Residential Landscaping**: Contribute to localized air quality improvement and aesthetic value.

Research Insights and Global Case Studies

1. NASA Clean Air Study (1989)

This foundational research highlighted the ability of certain ornamental plants to remove VOCs from enclosed spaces. It brought attention to the value of indoor plants in space stations and urban homes alike.

2. Indian Urban Studies

Research in Delhi and Mumbai showed that neighborhoods with higher green coverage had lower levels of suspended particulate matter (SPM) and nitrogen dioxide (NO_2).

3. Global Green City Initiatives

Cities like Singapore, Tokyo, and Vancouver have successfully integrated ornamental

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Figure 1: Ornamental Plants for Air Purification

vegetation in urban planning, leading to measurable reductions in air pollution levels.

Challenges in Implementation

Despite the potential benefits, several challenges hamper the large-scale adoption of ornamental plants as air purifiers:

- **Space Constraints:** Urban land use is often prioritized for development over greenery.
- **Maintenance Requirements:** Regular watering, pruning and pest control are necessary for effectiveness.
- **Lack of Awareness:** Many urban dwellers and policymakers are unaware of the air-purifying properties of ornamental plants.
- **Species Selection:** Choosing the wrong species for a particular climate or pollution load can reduce efficacy.

Recommendations for Effective Integration

To maximize the benefits of ornamental plants in air purification:

- **Policy Support:** Governments should promote urban forestry and incentivize green landscaping.
- **Urban Planning:** Integrate ornamental vegetation into building codes and zoning regulations.
- **Public Awareness Campaigns:** Educate citizens about the health and ecological benefits of ornamental plants.
- **Scientific Evaluation:** Continuously monitor pollutant removal capacity of different species to guide plant selection.
- **Sustainable Maintenance:** Use low-water-demand plants and organic fertilizers to reduce environmental impact.

Future Perspectives

1. Smart Green Infrastructure

Emerging technologies can enhance the role of ornamental plants:

- Sensor-integrated planters to monitor pollutant uptake.
- Drone-assisted urban greening for inaccessible areas.
- Mobile green walls for flexible deployment in polluted zones.

2. Genetic Improvements

Future research may focus on genetically enhancing the pollutant-absorbing capacity of ornamental plants without compromising their aesthetic appeal.

3. Community Involvement

Urban gardening movements, school-based greening projects, and citizen-led tree plantation drives can foster community engagement in sustainable practices.

Conclusion

Ornamental plants play a vital yet underappreciated role in purifying the air and enhancing environmental quality in urban areas. By capturing pollutants, moderating climate and providing psychological benefits, they serve as a bridge between human needs and ecological balance. Integrating ornamental plants into cityscapes not only contributes to pollution control but also promotes urban sustainability, resilience and quality of life. While challenges remain in terms of awareness, maintenance and policy, the path forward lies in recognizing the multifunctionality of ornamental plants and strategically embedding them into our living spaces. As cities grapple with the dual challenges of pollution and climate change, ornamental plants emerge as a green solution rooted in nature and sustained by science.

Reference

Kaur, J., Mudgal, G., & Dhar, S. K. (2025). Decoration Plants and Their Role in Remediation. In *Sustainable Remediation for Pollution and Climate Resilience* (pp. 695-724). Springer, Singapore.

Gupta, J. (2024). Role of Ornamental Plants in the Improvement of Environment. *Agriculture Association of Textile Chemical and Critical Reviews Journal*, *12*(1), 185-191.

Brilli, F., Fares, S., Ghirardo, A., de Visser, P., Calatayud, V., Muñoz, A., ... & Menghini, F. (2018). Plants for sustainable improvement of indoor air quality. *Trends in plant science*, *23*(6), 507-512.

Weidner, M., & Texeira, J. (2006). Potential and limitations of ornamental plants for indoor-air purification. *Floriculture, Ornamental Plant Biotechnol*, *4*, 54-63.

Rocha, C. S., Rocha, D. C., Kochi, L. Y., Carneiro, D. N. M., Dos Reis, M. V., & Gomes, M. P. (2022). Phytoremediation by ornamental plants: a beautiful and ecological alternative. *Environmental Science and Pollution Research*, 1-19.

Kaushal, A., Gupta, M., & Malik, J. A. (2022). Potential of Ornamental Plants for Phytoremediation. In *Bioremediation and Phytoremediation Technologies in Sustainable Soil Management* (pp. 23-45). Apple Academic Press.

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"Microplastics in the Environment: An Emerging Crisis for Ecosystems and Human Health"

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Microplastics, defined as plastic particles under 5 mm, are a widespread environmental pollutant impacting ecosystems and human health. They are either primary, created for products like cosmetics, or secondary, resulting from the breakdown of larger plastics. Due to their size and durability, microplastics are found in air, water, and soil, with ocean pollution expected to increase tenfold by 2025. Marine life faces risks from ingestion and bioaccumulation, causing physical harm and chemical toxicity. Humans are exposed mainly through seafood, potentially leading to health issues like oxidative stress, immune disorders, and exposure to harmful toxins. Despite growing awareness, regulations on microplastic contamination in food remain insufficient. This review summarizes current research on their sources, distribution, ecological effects, and health risks, highlighting the need for stronger mitigation efforts.

Keywords: Microplastics, Environmental contamination, Marine ecosystems, Human health risks

Introduction

Microplastics, particles under 5 mm, are a major environmental pollutant harming ecosystems and living organisms. They are categorized into primary microplastics, intentionally manufactured for uses like personal care products and synthetic textiles, and secondary microplastics, which result from the breakdown of larger plastic items. These particles are widespread, found in the air, water, and even remote areas, spreading globally due to their small size and lightweight nature. By 2025, ocean plastic could reach 250 million metric tons, a tenfold increase since 2010. Microplastics persist in the environment, accumulating over time and posing long-term risks. They have been linked to health problems in marine life, including reproductive issues and malnutrition. Microplastics also carry harmful pollutants, amplifying their toxicity. As these pollutants enter the food chain, they ultimately pose risks to human health. Growing awareness has led to government actions, including bans on primary microplastics.

Occurrence, size and type of plastics

Plastics enter oceans mainly through road runoff (66%), wastewater (25%), and wind (7%) (Plastics Europe, 2016). Microplastics (1–10 mm), from materials like PE, PS, and PP, originate from packaging and fishing gear, which absorb pollutants such as PCBs, DDTs, and heavy metals. Marine organisms like fish and mussels ingest these particles, posing threats to ecosystems and human health. Microplastics enter fish through gills or digestion, with smaller particles reaching organs like the liver, causing

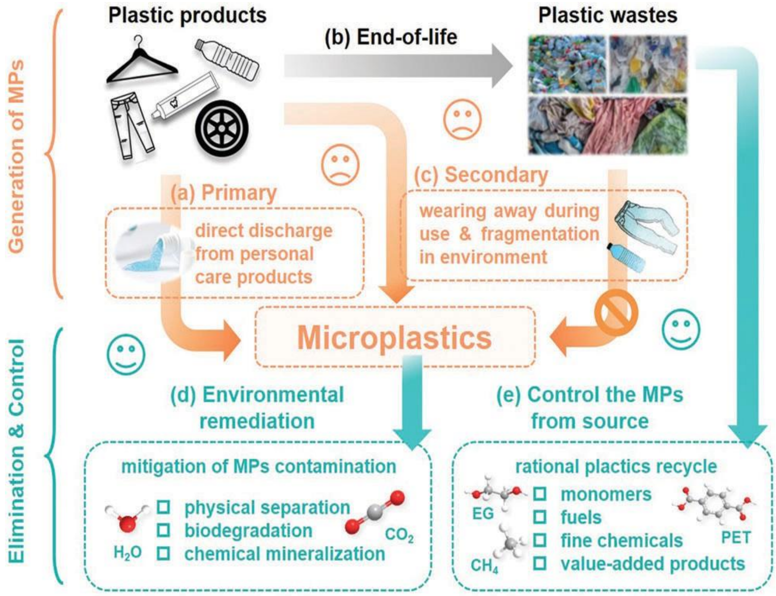

Figure 1. Sources of Microplastics (MPs) and Strategies for Achieving an MP-Free Environment.
(a) Generation of primary MPs (b) Disposal and end-of-life processes of plastic products. (c) Formation of secondary MPs from plastic waste. (d) Chemical breakdown of existing MPs in the environment. (e) Effective waste management strategies to reduce MP generation at key sources.

inflammation, oxidative stress, and metabolic disruption, ultimately affecting food safety.

Impacts of microplastics in aquatic ecosystems

Microplastics threaten marine life as they are easily ingested by organisms like plankton, fish, and benthic species. Once consumed, they can move up the food chain through trophic transfer, as noted by Wright et al. (2013). Microplastics ingested by smaller creatures, such as plankton, are passed to larger predators, including fish, and ultimately to humans through seafood consumption. The effects of microplastic ingestion vary, from physical blockages in digestive systems to chemical toxicity from absorbed pollutants. These impacts are detailed in Table 1, which outlines how microplastics affect different species and ecosystems.

Factors influencing microplastic ingestion in marine ecosystem

Physical properties

The size and density of microplastics determine which organisms ingest them and where they accumulate in the water column. Smaller particles are often mistaken for prey by similarly sized feeders (Andrady, 2011). Low-density plastics like PS, PP, and PE float and are consumed by surface feeders such as copepods, while denser plastics like PET and PVC sink, making them accessible to bottom-dwelling species (Cole et al., 2013). Microplastics are redistributed by natural forces like bioturbation and storms. Over time, they change in size, shape, and density due to microbial colonization and photo-oxidation, altering their buoyancy and ecological impact (Rummel et al., 2016).

Presence of biofilms

Biofouling, the buildup of microorganisms and organic matter on plastics, makes microplastics resemble food to marine life (Kooi et al., 2017). Biofilms alter their vertical movement and attract species using chemical cues. For instance, shorebirds respond to dimethyl sulfide from biofilms (Savoca et al., 2016). Even copepods prefer biofouled over clean particles (Vroom et al., 2016), showing biofouling affects a wide range of species. Understanding these interactions is key to addressing microplastic impacts on marine ecosystems.

Table1. Impacts of microplastics on marine organisms

Marine Organisms	Impacts of Microplastics	References
Microalgae	Reduced photosynthesis and growth.	Bhattacharya et al., (2010)
Copepods	Lower hatching success, survival, reproduction, feeding capacity, and lipid content.	Cole et al., (2014)
Fish	Gut blockages, chemical transfer, reduced feeding, inflammation, oxidative stress, and metabolic disruption.	Ory et al., (2018); Cheung et al., (2018)
Crustaceans	Reduced fecundity, delayed offspring development, impaired feeding, altered enzyme activity, and behavioral changes.	Cole et al., (2015)
Benthos	Ingestion of sinking and sediment-associated microplastics by suspension and deposit feeders.	Wright et al., (2013); Egbeocha et al., (2018)
Molluscs	Decreased filtration efficiency in mussels, altered feeding, reproductive issues in oysters, and potential human exposure.	Sussarellu et al., (2016); Baird (2016); Naji et al., (2019)
Coral Reefs	Reduced calcification, skeletal growth, and mineralization rates.	Reichert et al., (2018)
Marine Plants	Prevalence of microplastics (polyethylene, polypropylene, polystyrene) in mangrove sediments.	Barasarathi et al., (2014); Li et al., (2018)
Humans	The human body's excretory system eliminates microplastics by disposing of > 90% of the ingested micro and nanoplastics via feces	Da Costa et al., (2016)

Assimilation by marine organisms

Microplastics are increasingly found in marine organisms across all trophic levels, from zooplankton to marine mammals. Their small size, similar to plankton and sand particles, makes them easily accessible to various species. Non-selective feeders, such as filter feeders, are particularly at risk as they consume large volumes of water or sediment, ingesting microplastics alongside food (Browne et al., 2008; Cole et al., 2013; Farrell and Nelson, 2013). Nanoplastics can enter the food web through algae, bacteria, or filter feeders (Koelmans et al., 2015; Mattsson et al., 2015), and their small size enables them to disrupt biological functions, such as blood cell activity and photosynthesis (Galloway, 2015). However, detecting nanoplastics is difficult due to the limitations of current analytical methods, which include UV-VIS spectrometry, electron microscopy, and dynamic light scattering (von der Kammer et al., 2012). Improved techniques are needed to better understand their distribution and impact on marine ecosystems.

Marine Organisms' Reactions and Adaptations to Microplastic Pollution

Marine organisms interact with microplastics through ingestion, entanglement, or using them as habitats, causing harm to individuals, populations, and ecosystems. Many species, from plankton to large predators, accidentally consume microplastics, leading to digestive blockages, nutrient loss, and toxic effects, impacting health, reproduction, and survival. Filter feeders like mussels and oysters are particularly vulnerable. These impacts cascade up the food chain, disrupting predator health and ecosystem stability. Entanglement in larger plastics or microplastic aggregates can also cause injuries, limit movement, and reduce foraging success, especially in sea turtles and marine mammals.

Effect of microplastics on human health with emphasis on microplastics.

Shellfish and their products

Seafood can be contaminated with microplastics through ingestion, surface adhesion, and during processing (Cole et al., 2013; EFSA, 2016). For instance, studies have shown that popular European seafood items like Mytilus edulis (mussels) contain an average of 0.36 ± 0.07 microplastic particles per gram of soft tissue, while *Crassostrea gigas* (Pacific oysters) contain 0.47 ± 0.16 microplastic particles per gram of soft tissue at the point of human consumption (Van Cauwenberghe and Janssen, 2014). In fish, microplastics are mainly in the digestive tract and minimal in muscle (Mercogliano et al., 2020).

These findings reveal the widespread presence of microplastics in seafood and their entry into the human food chain, raising serious health concerns. Associated pollutants can cause reduced birth weight (Cabrera et al., 2019), childhood obesity, hypertension (Vafeiadi et al., 2015), and endocrine disruption (Hertz et al., 2008; Papadopoulou et al., 2013). Heavy metals like mercury, lead, and cadmium on microplastics may also promote antibiotic resistance by co-selecting harmful pathogens (Imran et al., 2019). Despite these risks, regulation and monitoring of microplastics in seafood remain limited, underscoring the need for further research and stricter policies (Ziccardi et al., 2016).

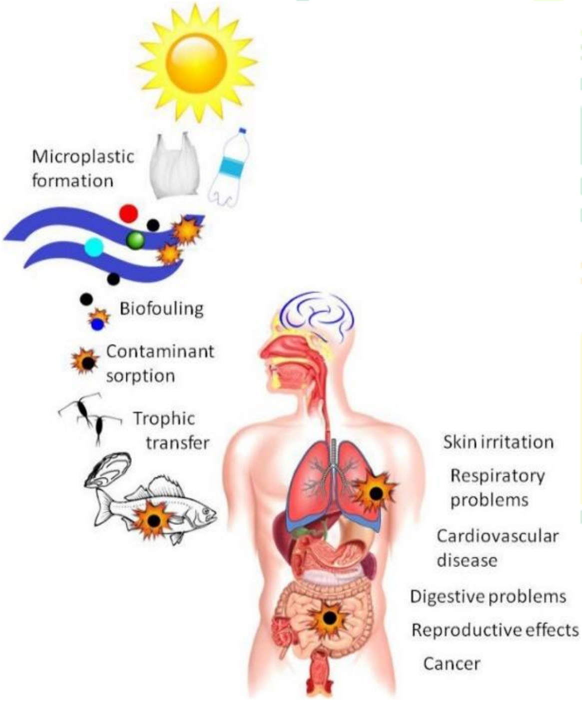

Figure 2. Potential health effects resulting from the bioaccumulation and biomagnification of microplastics and chemical contaminants in the human body.

Conclusion

The growing presence of microplastics in the environment poses a serious threat to marine ecosystems and human health. These particles, originating from both direct production and the breakdown of larger plastics, infiltrate the food chain, causing physical and chemical harm to marine organisms and potentially impacting human health through seafood consumption. Microplastics act as carriers of toxic pollutants, worsening their ecological and health effects. While some marine species show limited adaptations or excretion of microplastics, their widespread presence highlights the need for global action. Research gaps, especially regarding the long-term effects of nanoplastics and detection methods, call for increased scientific efforts. Policymakers must prioritize regulations to reduce plastic pollution, promote sustainable alternatives, and set safety standards for microplastic contamination in food. A collaborative approach across science, industry, and government is crucial to addressing this growing threat.

References

Andrady, A. L. (2011). Microplastics in the marine environment. *Marine pollution bulletin*, *62*(8), 1596 1605.

Baird, C. A. (2016). *Measuring the effects of microplastics on sponges* (Doctoral dissertation, Open Access Te Herenga Waka-Victoria University of Wellington).

Barasarathi, J., Agamuthu, P., Emenike, C. U., & Fauziah, S. H. (2014, August). Microplastic abundance in selected mangrove forest in Malaysia. In *Proceeding of the ASEAN Conference on Science and Technology* (Vol. 5, pp. 18-20). ASEAN.

Bhattacharya, P., Lin, S., Turner, J. P., & Ke, P. C. (2010). Physical adsorption of charged plastic nanoparticles affects algal photosynthesis. *The journal of physical chemistry C*, *114*(39), 16556-16561.

Browne, M. A., Dissanayake, A., Galloway, T. S., Lowe, D. M., & Thompson, R. C. (2008). Ingested microscopic plastic translocates to the circulatory system of the mussel, Mytilus edulis (L.). *Environmental science & technology*, *42*(13), 5026-5031.

Cabrera-Rodríguez, R., Luzardo, O. P., Almeida-González, M., Boada, L. D., Zumbado, M., Acosta-Dacal, A., ... & Henríquez-Hernández, L. A. (2019). Association between prenatal exposure to multiple persistent organic pollutants (POPs) and growth indicators in newborns. *Environmental Research*, *171*, 285-292.

Cheung, L. T., Lui, C. Y., & Fok, L. (2018). Microplastic contamination of wild and captive flathead grey mullet (Mugil cephalus). *International journal of environmental research and public health*, *15*(4), 597.

Cole, M., Lindeque, P., Fileman, E., Halsband, C., & Galloway, T. S. (2015). The impact of polystyrene microplastics on feeding, function and fecundity in the marine *copepod Calanus helgolandicus. Environmental Science & Technology*, *49*(2), 1130–1137.

Cole, M., Lindeque, P., Fileman, E., Halsband, C., Goodhead, R., Moger, J., & Galloway, T. S. (2013). Microplastic ingestion by zooplankton. *Environmental science & technology*, *47*(12), 6646-6655.

Cole, M., Webb, H., Lindeque, P. K., Fileman, E. S., Halsband, C., & Galloway, T. S. (2014). Isolation of microplastics in biota-rich seawater samples and marine *organisms. Scientific Reports*, *4*, 4528.

Da Costa, J. P., Santos, P. S., Duarte, A. C., & Rocha-Santos, T. (2016). (Nano) plastics in the EFSA Panel on Contaminants in the Food Chain (CONTAM). (2016). Presence of microplastics and nanoplastics in food, with particular focus on seafood. *Efsa Journal*, *14*(6), e04501.

Egbeocha, C. O., Malek, S., Emenike, C. U., & Milow, P. (2018). Feasting on microplastics: Ingestion by and effects on marine organisms. *Aquatic Biology*, *27*, 93–106.

Farrell, P., & Nelson, K. (2013). Trophic level transfer of microplastic: Mytilus edulis (L.) to Carcinus maenas (L.). *Environmental pollution*, *177*, 1-3.

Galloway, T. S. (2015). Micro-and nano-plastics and human health. *Marine anthropogenic litter*, 343-366.

Hertz-Picciotto, I., Park, H. Y., Dostal, M., Kocan, A., Trnovec, T., & Sram, R. (2008). Prenatal exposures to persistent and non-persistent organic compounds and effects on immune system development. *Basic & clinical pharmacology & toxicology*, *102*(2), 146-154.

Imran, M., Das, K. R., & Naik, M. M. (2019). Co-selection of multi-antibiotic resistance in bacterial pathogens in metal and microplastic contaminated environments: An emerging health threat. *Chemosphere*, *215*, 846-857.

Koelmans, A. A., Besseling, E., & Shim, W. J. (2015). Nanoplastics in the aquatic environment. Critical review. *Marine anthropogenic litter*, 325-340.

Kooi, M., Nes, E. H. V., Scheffer, M., & Koelmans, A. A. (2017). Ups and downs in the ocean: effects of biofouling on vertical transport of microplastics. *Environmental science & technology*, *51*(14), 7963-7971.

Li, J., Liu, H., & Chen, J. P. (2018). Microplastics in freshwater systems: A review on occurrence, environmental effects, and methods for microplastics detection. *Water research*, *137*, 362-374.

Mattsson, K., Hansson, L.-A., & Cedervall, T. (2015). Nano-plastics in the aquatic environment. *Environmental Science: Processes & Impacts*, *17*(10), 1712–1721.

Mercogliano, R., Avio, C. G., Regoli, F., Anastasio, A., Colavita, G., & Santonicola, S. (2020). Occurrence of microplastics in commercial seafood under the perspective of the human food chain. A review. *Journal of agricultural and food chemistry*, *68*(19), 5296-5301.

Naji, A., Nuri, M., Amiri, P., & Niyogi, S. (2019). Small microplastic particles (S-MPPs) in sediments of mangrove ecosystem on the northern coast of the Persian Gulf. *Marine pollution bulletin*, *146*, 305-311.

Ory, N., Chagnon, C., Felix, F., Fernández, C., Ferreira, J. L., Gallardo, C., Ordonez, O. G., Henostroza, A., Laaz, E., Mizraji, R., & Mojica, H. (2018). Low prevalence of microplastic contamination in planktivorous fish species from the southeast Pacific Ocean. *Marine Pollution Bulletin, 127*, 211–216.

Papadopoulou, E., Vafeiadi, M., Agramunt, S., Mathianaki, K., Karakosta, P., Spanaki, A., ... & Kogevinas, M. (2013). Maternal diet, prenatal exposure to dioxins and other persistent organic pollutants and anogenital distance in children. *Science of the total environment*, *461*, 222-229.

Reichert, J., Schellenberg, J., Schubert, P., & Wilke, T. (2018). Responses of reef building corals to microplastic exposure. *Environmental Pollution*, *237*, 955-960.

Rummel, C. D., Löder, M. G., Fricke, N. F., Lang, T., Griebeler, E. M., Janke, M., & Gerdts, G. (2016). Plastic ingestion by pelagic and demersal fish from the North Sea and Baltic Sea. *Marine pollution bulletin*, *102*(1), 134-141.

Savoca, M. S., Wohlfeil, M. E., Ebeler, S. E., & Nevitt, G. A. (2016). Marine plastic debris emits a keystone infochemical for olfactory foraging seabirds. *Science advances*, *2*(11), e1600395.

Sussarellu, R., Suquet, M., Thomas, Y., Lambert, C., Fabioux, C., Pernet, M. E. J., ... & Huvet, A. (2016). Oyster reproduction is affected by exposure to polystyrene microplastics. *Proceedings of the national academy of sciences*, *113*(9), 2430-2435.

Vafeiadi, M., Georgiou, V., Chalkiadaki, G., Rantakokko, P., Kiviranta, H., Karachaliou, M., ... & Chatzi, L. (2015). Association of prenatal exposure to persistent organic pollutants with obesity and cardiometabolic traits in early childhood: the Rhea mother–child cohort (Crete, Greece). *Environmental health perspectives*, *123*(10), 1015-1021.

Van Cauwenberghe, L., & Janssen, C. R. (2014). Microplastics in bivalves cultured for human consumption. *Environmental pollution*, *193*, 65-70.

Von der Kammer, F., Ferguson, P. L., Holden, P. A., Masion, A., Rogers, K. R., Klaine, S. J., ... & Unrine, J. M. (2012). Analysis of engineered nanomaterials in complex matrices (environment and biota): general considerations and conceptual case studies. *Environmental Toxicology and Chemistry*, *31*(1), 32-49.

Vroom, R., Halsband, C., Besseling, E., & Koelmans, A. A. (2016). Effects of microplastics on zooplankton: microplastic ingestion: the role of taste. In *ICES/PICES 6th Zooplankton Production Symposium: New Challenges in a Changing Ocean*.

Wright, S. L., Thompson, R. C., & Galloway, T. S. (2013). The physical impacts of microplastics on marine organisms: a review. *Environmental pollution*, *178*, 483-492.

Ziccardi, L. M., Edgington, A., Hentz, K., Kulacki, K. J., & Kane Driscoll, S. (2016). Microplastics as vectors for bioaccumulation of hydrophobic organic chemicals in the marine environment: A state-of-the-science review. *Environmental toxicology and chemistry*, *35*(7), 1667-1676.

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Ways and means to improve nutrient use efficiency in finger millet

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Introduction:

Finger millet (*Eleusine coracana*) is the fourth most important millet after sorghum, pearl millet and foxtail millet belongs to the family Poaceae. It is also known as ragi in Kannada, Kelvragu in Tamil, ragalu in Telugu and muttari in Malayalam. It is grown for both for grain and forage. Green straw suitable for making silage. The uniqueness in finger millet is the richest source of calcium (300-350 mg/100 g grain). Finger millet is cultivated in nearly 1159.40 thousand hectares area with the production of 1998.36 thousand tonnes and average productivity 1724 kg ha^{-1}.

Karnataka is higher producer of finger millet in terms of area, production and productivity with 9.16 lakh ha, 14.02 lakh tonnes and 1611 kg ha^{-1}. In Karnataka, it is mainly grown in Haveri, Ballari, Chitradurga, Mandya, Mysuru and Bengaluru districts.

Importance of finger millet:

- **Grown for grain and fodder purpose**
- Highly valued by traditional farmers
- Requires low inputs
- Short duration
- Highly nutritious
- Drought tolerant
- Wide utility in processing and value addition

Major constraints in finger millet production:

- Low nutrient replenishment
- Disease outbreaks
- Unscientific land management practices
- Land degradation
- Low soil fertility levels
- High weed menance
- Poor crop management
- Imbalanced / improper use of fertilizers
- Traditional farming practices

Nutrients necessary for finger millet production:

- **Basic nutrients:** Carbon, Hydrogen, Oxygen
- **Macronutrients:** Nitrogen, Phosphorus, Potassium, Sulphur
- **Micronutrients:** Iron, Zinc, Boron, Manganese, Copper etc.,

Important role of some nutrients in finger millet production

1. **Nitrogen**- Essential for plant growth and development, and it also plays a role in photosynthesis and grain filling.
2. **Phosphorus** - Essential for root development, flowering, and grain formation.
3. **Potassium** - Essential for water uptake, photosynthesis, and stress tolerance.
4. **Sulphur** - Essential for protein synthesis and crop health.
5. **Iron** - Essential for chlorophyll production and photosynthesis. It is also involved in the transport of oxygen and carbon dioxide in the plant.

6. **Zinc** - Essential for protein synthesis and growth. It is also involved in the production of auxins, which are hormones that regulate plant growth.
7. **Boron** - Essential for cell division and the transport of sugars and amino acids in the plant. It is also involved in the development of the reproductive organs.
8. **Manganese** - Essential for photosynthesis and respiration. It is also involved in the production of enzymes that break down carbohydrates and proteins.
9. **Copper** - Essential for the production of chlorophyll and the absorption of iron. It is also involved in the production of enzymes that protect the plant from oxidative damage.

Nutrient use efficiency:

There is increased demand for fertilizer nutrients to meet the global demand for food. However, there are inadequate fertilizer resources available and rising public concern related to nutrient side effects. Estimates of overall efficiency of applied fertilizer have been reported to be lesser than 50% for nitrogen, less than 10% for phosphorous and about 40% for potassium. This has led to need for Nutrient use efficiency to be improved. Placing the nutrients at right rate, time, place and method will increase the nutrient use efficiency thereby enhancing the crop productivity.

Nutrient use efficiency is defined as the amount of dry matter produced per unit of nutrient applied or absorbed.

- Nutrient use efficiency depends on plant's ability to take up nutrients efficiently from the soil.
- Better uptake and enhanced utilization efficiency are two pathways by which nutrient use efficiency can be improved.
- The objective of nutrient use efficiency is to increase the overall performance of crop by providing economically optimum nourishment to the crop plants.

Factors effecting Nutrient use efficiency:

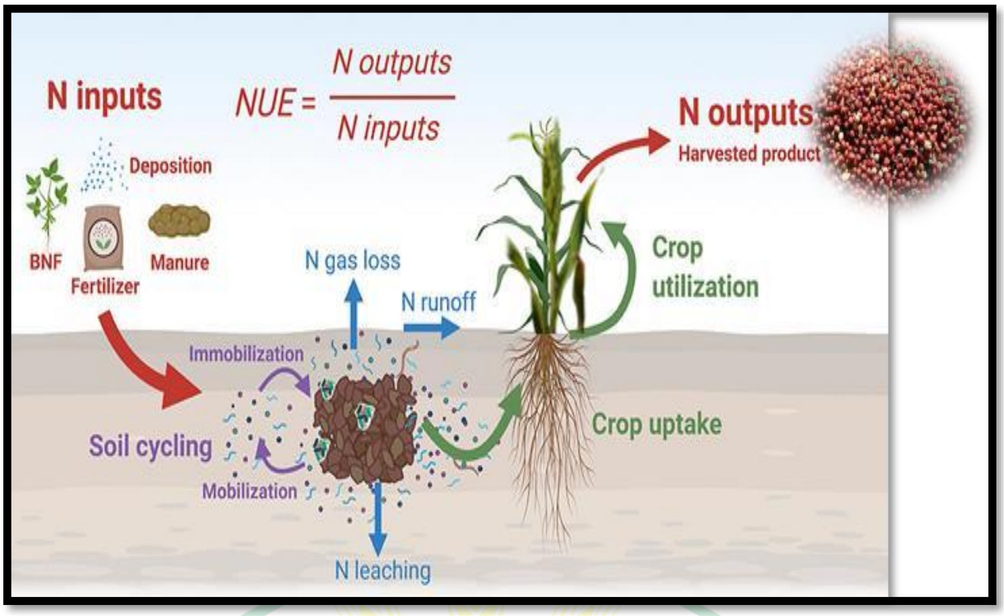
- **Soil properties and nature of fertilizers:** Nitrogenous fertilizers are lost into deeper layers beyond root zone if the entire quantity of fertilizer is applied especially in light textured soils.
- **Nature of the Soil:** Soil properties like texture, pH, CEC, nutrient and moisture status are important factors to be considered for selecting suitable method of application.
- **Nature of the Crop:** Depending on the type of root system and spacing adopted for the crop, different methods of fertilizer application are practiced.
- **Nature of the fertilizer:** Suitable method of fertilizer application depends on the properties of fertilizers such as physical form, solubility and mobility.
- **Methods of fertilizer application:** It is a process where the fertilizer is spread over the entire soil area evenly and uniformly.

Ways to improve nutrient use efficiency:

- ✓ Varietal selection
- ✓ Seed treatment
- ✓ Nutrient management
- ✓ Establishment techniques
- ✓ Intercropping
- ✓ Precision management
- ✓ Water management
- ✓ Weed management

Nutrient expert based nutrient management:

1. **Right rate:** Most crops are location and season Specific depending on cultivar, management practices, climate, etc., and so it is critical that realistic yield



goals are established and that nutrients are applied to meet the target yield.

2. **Right Time:** Greater synchronization between crop demand and nutrient supply is necessary to improve nutrient use efficiency, especially for N.
3. **Right Place:** Fertilizer application method has always been critical in ensuring nutrients are used efficiently. Determining the right placement is as important as determining the right application rate. Various placements are available, but most commonly used surface or subsurface applications before or after planting.
4. **Right Source:** Ensure the nutrient applied is plant-available or is in a form that converts into a plant-available form in the soil in a timely manner.

Precision nutrient management:

Chlorophyll meter:

- Chlorophyll meter can be used to estimate the N content of crop, in general most of the N found in the chloroplast of plant (Olesen *et al.*, 2004). It helps to recommend the nitrogen fertilizer.
- It has ability to self-calibrate for different soils, climate and crop varieties.
- It is also recommended to assess the effectiveness of late applied nitrogen in standing crops to increase grain yield and protein content (Singh *et al.*, 2012).

Leaf color chart:

- ✓ Simple leaf colour chart (LCC) is a simple tool which is a proxy for leaf N is used as an indicator of leaf color, leaf color intensity, leaf N status and right time of N application.
- ✓ LCC is a diagnostic tool which can help farmers for making appropriate decisions regarding the need for nitrogen fertilizer applications in standing crops.
- ✓ Conceptually it is based on the measurement of relative greenness of plant leaves which directly co-related with its chlorophyll content.

Nitrogen is a principle component of leaf chlorophyll so its measurement over various phenological stages serves as the indirect basis for nitrogen management in rice.

Reference:

Aparna, K., Rekha, K. B., Vani, K. P. and Prakash, T. R., 2020, Nutrient uptake and quality parameters of finger millet as influenced by crop residue composting. *Int. J. Comput. Sci.*, **8**(3): 2331-2335.

Ashrafi, M. R., Singh, M. K., Tyagi, S., Kumar, A. and Shambhavi, S., 2020, Effect of weed management practices on transplanted finger millet (*Eleusine coracana* L.) in Bihar. *Int. J. Comput. Sci.*, **8**(5): 211-214.

Basavaraja, P. K., Saqeebulla, H. M., Dey, P and Patil, S., 2017, Evaluation of different approaches of fertilizer recommendation on finger millet (*Eleusine coracana* L) yield, nutrient requirement and economics. *Int. J. Farm Sci.*, **7**(2): 102-107.

Chavan I B, Jagtap D N and Mahadkar, U. V., 2018, Effect of different establishment techniques, levels and time of application of nitrogen on partitioning of dry matter in finger millet (Eleusine coracana L.). *Farming and Management*, **3**(2): 107-109.

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Emerging Vector-Borne Diseases in Agricultural Crops: Entomological Insights into Insect-Transmitted Pathogens

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The increasing prevalence of vector-borne plant diseases presents a growing threat to global agricultural sustainability and food security. Insect vectors such as aphids, whiteflies, thrips, leafhoppers, and planthoppers transmit a wide array of viruses, phytoplasmas, and bacteria that severely affect the health and productivity of major crops, including rice, wheat, maize, cotton, tomato, and potato. Changes in agricultural practices, climate variability, vector migration, and international trade have contributed to the emergence and re-emergence of these diseases. This article reviews the most important crop-specific vector-pathogen complexes, their epidemiology, entomological dynamics, and integrated management strategies, emphasizing the critical role of entomologists in monitoring and controlling vector-borne plant diseases.

Keywords: Vector-borne plant diseases, insect vectors, viral pathogens, major crops, aphids, whiteflies, phytoplasmas, integrated pest management

1. Introduction

Vector-borne plant diseases, caused by insect-mediated transmission of pathogens, are emerging as a major threat to global crop production. Rapid agricultural expansion, globalization, climate variability, and ecological changes have increased the interaction between vectors, crops, and pathogens, resulting in the emergence and re-emergence of devastating plant diseases.

2. Key Insect Vectors and Associated Major Crop Diseases

2.1 Whiteflies (*Bemisia tabaci*)

Crops Affected: Tomato, cotton, cassava, cucurbits

Diseases:

- **Tomato yellow leaf curl virus (TYLCV)**: One of the most destructive diseases in tomato cultivation worldwide. Causes leaf curling, yellowing, and stunted growth.
- **Cassava mosaic disease (CMD)**: Transmitted by *Bemisia tabaci* in sub-Saharan Africa, causes chlorosis, distorted leaves, and tuber loss.
- **Cotton leaf curl virus (CLCuV)**: A major disease of cotton in South Asia and parts of Africa.

Remarks: *Bemisia tabaci* species complex is notorious for its rapid reproduction, insecticide resistance, and efficient virus transmission (Navas-Castillo et al., 2011).

2.2 Aphids (*Myzus persicae, Rhopalosiphum maidis, Aphis gossypii*)

Crops Affected: Potato, sugar beet, wheat, maize, cucurbits

Diseases:

- **Potato virus Y (PVY)** and **Potato leafroll virus (PLRV)**: Transmitted by *M. persicae*, these viruses result in mosaic patterns, necrosis, and yield decline.
- **Barley yellow dwarf virus (BYDV)**: Common in cereals like wheat and barley, spread by *R. maidis*.
- **Cucumber mosaic virus (CMV)**: Affects over 1,200 plant species, causing mosaic symptoms and flower malformation.

Remarks: Aphids transmit many non-persistent and persistent viruses, often within minutes of feeding. Their wide host range and rapid population growth exacerbate their impact (Ng & Perry, 2004).

2.3 Thrips (*Frankliniella occidentalis*, *Thrips palmi*)

Crops Affected: Tomato, chili, groundnut, onion, ornamentals

Diseases:

- **Tomato spotted wilt virus (TSWV)**: Causes necrotic rings, leaf bronzing, and fruit deformation.
- **Groundnut bud necrosis virus (GBNV)**: A serious constraint in peanut cultivation in India.
- **Iris yellow spot virus (IYSV)**: Affects onion and garlic crops.

Remarks: Thrips are cryptic feeders and transmit tospoviruses in a persistent-propagative manner. Vector acquisition occurs during the larval stage, complicating control (Rotenberg et al., 2015).

2.4 Leafhoppers and Planthoppers (*Nephotettix virescens*, *Nilaparvata lugens*)

Crops Affected: Rice, maize, sugarcane

Diseases:

- **Rice tungro virus complex**: Transmitted by *Nephotettix virescens*, causing yellow-orange leaf discoloration and stunted growth.
- **Rice ragged stunt virus (RRSV)** and **Rice grassy stunt virus (RGSV)**: Spread by *Nilaparvata lugens* (brown planthopper), which also causes direct damage.
- **Maize streak virus (MSV)**: Transmitted by *Cicadulina spp.*, causes streaks on leaves and severe stunting.

Remarks: These vectors cause both direct and indirect damage and are responsible for massive yield losses in staple cereals (Hibino, 1996).

2.5 Psyllids (*Bactericera cockerelli*)

Crops Affected: Tomato, potato

Diseases:

- **Zebra chip disease**: Caused by *Candidatus Liberibacter solanacearum*, leads to striped necrosis in potato tubers.
- **Remarks**: Psyllid-transmitted pathogens often go undetected until late stages, and control requires early season vector suppression (Munyaneza, 2012).

Several groups of insects serve as key vectors for plant pathogens. Notable among them are whiteflies, aphids, thrips, leafhoppers, planthoppers, and psyllids. These vectors transmit viruses, phytoplasmas, and bacteria that damage economically important crops. This section details the major vectors, diseases, and their crop hosts.

Vector	Group	Pathogen Type	Disease	Major Crop(s)
Aphids (*Aphis spp.*, *Myzus persicae*)	Hemiptera	Virus	Potato Virus Y, Cucumber Mosaic Virus (CMV), Barley Yellow Dwarf Virus	Potato, cucurbits, cereals
Whiteflies (*Bemisia tabaci*)	Hemiptera	Virus	Tomato Yellow Leaf Curl Virus (TYLCV), Cotton Leaf Curl Virus (CLCuV), Cassava Mosaic Virus	Tomato, cotton, cassava
Leafhoppers (*Nephotettix virescens*)	Hemiptera	Virus/Phytoplasma	Rice Tungro Virus, Grassy Shoot Disease	Rice
Planthoppers (*Nilaparvata lugens*)	Hemiptera	Virus	Rice Ragged Stunt Virus, Rice Grassy Stunt Virus	Rice
Thrips (*Frankliniella occidentalis*)	Thysanoptera	Virus	Tomato Spotted Wilt Virus (TSWV), Groundnut Bud Necrosis Virus (GBNV)	Tomato, groundnut, chili
Psyllids (*Bactericera cockerelli*)	Hemiptera	Bacteria	Zebra Chip Disease (caused by *Candidatus Liberibacter solanacearum*)	Potato, tomato
Nephotettix virescens	Hemiptera	Virus	Rice Tungro Virus	Rice
Pyrilla perpusilla	Hemiptera	MLO	Grassy shoot disease	Sugarcane
Yamatotettix flavovittatus	Hemiptera	MLO	White leaf disease	Sugarcane
Peregrinus maidis	Hemiptera	Virus	Maize mosaic virus	Maize
Peregrinus maidis	Hemiptera	Virus	Maize stripe virus	Maize
Atherigona approximata	Diptera	Fungus (Claviceps fusiformis)	Ergot disease	Pearl millet
Rhopalosiphum maidis	Hemiptera	Virus	Red leaf stripe virus	Sorghum
Bemisia tabaci	Hemiptera	Virus (Begomovirus)	Leaf curl virus	Cotton
Bemisia tabaci	Hemiptera	Virus (Begomovirus)	Yellow vein mosaic virus	Bhindi (Okra)
Bemisia tabaci	Hemiptera	Virus (Begomovirus)	Leaf curl virus	Tomato
Thrips palmi	Thysanoptera	Virus (Tospovirus)	Bud necrosis virus	Groundnut
Aphis craccivora	Hemiptera	Virus (Peanut stripe virus)	Stripe virus	Groundnut
Bemisia tabaci	Hemiptera	Virus	Leaf curl / Mosaic complex	Chilli
Hishimonus phycitis	Hemiptera	Phytoplasma (MLO)	Little leaf disease	Brinjal (Eggplant)
Bemisia tabaci	Hemiptera	Virus (Begomovirus)	Leaf curl	Papaya
Aphis gossypii	Hemiptera	Virus (Cucumber mosaic virus)	Mosaic virus	Cucurbits
Myzus persicae	Hemiptera	Virus (Potato leaf roll)	Leaf roll virus	Potato
Myzus persicae	Hemiptera	Virus (Mosaic virus)	Potato mosaic	Potato
Pentalonia nigronervosa	Hemiptera	Virus (BBTV)	Banana bunchy top	Banana
Toxoptera citricida	Hemiptera	Virus (Tristeza virus)	Citrus tristeza	Citrus
Planococcus ficus	Hemiptera	Virus (Leaf roll virus)	Grapevine leaf roll	Grapevine
Diaphorina citri	Hemiptera	Bacteria (Liberibacter)	Citrus greening	Pomegranate
Eriophyes mangiferae	Acarina (Mite)	Unknown / Fungal	Mango malformation	Mango
Bemisia tabaci	Hemiptera	Virus (Begomovirus)	Leaf curl virus	Tobacco

Transmission Mechanisms

- **Non-persistent**: Quick transmission; virus is carried briefly (e.g., CMV by aphids)
- **Persistent-circulative**: Virus circulates in the vector before transmission (e.g., TYLCV by whiteflies)
- **Propagative**: Virus replicates in vector (e.g., TSWV in thrips)

3. Drivers of Emergence and Re-Emergence

Multiple factors contribute to the emergence of vector-borne crop diseases, including climatic changes, intensification of monoculture farming, insecticide resistance, and increased global movement of plant material. Understanding these drivers is essential for forecasting and mitigation.

3.1 Climate Change and Environmental Stress

Increased temperature, altered precipitation patterns, and extreme weather events modify the phenology, reproduction, and migration of vectors. For instance, *Bemisia tabaci* populations thrive in warmer climates, expanding their distribution into temperate regions.

3.2 Monoculture and Intensive Farming

Continuous cropping and lack of plant diversity favour vector population build-up and disease spread. Cropping synchrony increases vulnerability during peak vector activity.

3.3 Global Trade and Plant Material Movement

International exchange of infected planting material and ornamental plants has introduced both vectors and pathogens across borders (Jones, 2021).

3.4 Pesticide Misuse and Resistance

Excessive use of broad-spectrum insecticides disrupts ecological balance and selects for resistant vector biotypes. This has been notably problematic in *B. tabaci*, leading to recurring outbreaks.

4. Surveillance and Detection Techniques

- **Vector Identification**: Morphological and molecular tools (COI barcoding) for species-level identification.
- **Pathogen Detection**: ELISA, PCR, and next-generation sequencing (NGS) for accurate pathogen profiling.
- **Remote Sensing and Modelling**: GIS mapping of vector hotspots, climate-based forecasting tools.

National programs such as India's **NIBSM** and Europe's **EPPO** collaborate with entomologists for early detection and containment.

5. Integrated Disease and Vector Management

Management of vector-borne plant diseases requires a holistic approach that includes cultural practices, biological control, host resistance, and judicious chemical use. This section outlines the current integrated management strategies for controlling vector populations and limiting disease spread.

5.1. Cultural and Agronomic Measures

- Crop rotation, intercropping, and removal of alternate hosts.
- Timely sowing and rogueing of infected plants.

5.2. Biological Control

- Release of parasitoids (e.g., Encarsia formosa for whiteflies)
- Use of entomopathogenic fungi and predators (e.g., lady beetles)

5.3. Host Plant Resistance

- Breeding for virus-tolerant and vector-resistant varieties (e.g., PVY-resistant potatoes, TYLCV-tolerant tomatoes)

5.4. Judicious Insecticide Use

- Targeted application during vector migration windows Rotation of insecticide groups to delay resistance

5.5. RNAi and Biotechnological Approaches

Gene silencing technologies targeting vector feeding or virus transmission are under development and show promise for future applications.

5.6. Vector Monitoring and Forecasting

- Yellow sticky traps for whiteflies and aphids
- Light traps for planthoppers and leafhoppers
- Forecast models based on vector population dynamics and weather

6. Future Outlook and Research Priorities

- **Pathogen–Vector–Host Interaction Studies**: Understanding the molecular mechanisms of transmission and virulence.
- **Climate-Resilient IPM Models**: Incorporating predictive analytics and real-time surveillance.
- **Regulatory Frameworks**: Strengthened phytosanitary measures and quarantine protocols.

Collaborative research among entomologists, virologists, breeders, and climate scientists is essential to build adaptive, long-term solutions to crop vector-borne diseases.

7. Conclusion

Insect-vectored diseases pose one of the most complex and under-acknowledged threats to crop health globally. With the convergence of ecological, agronomic, and socio-economic drivers accelerating disease emergence, entomologists are at the forefront of an urgent battle. A holistic, systems-based approach—integrating surveillance, vector biology, cultural control, resistance breeding, and policy support—is imperative to protect crops and ensure food security in a rapidly changing world. **Vectors do not always cause visible damage, but they are more dangerous as carriers of diseases.** Many vector-transmitted pathogens are **systemic**—once inside the plant, they are hard to eliminate. **IPM (Integrated Pest Management)** remains the most sustainable method for long-term vector and disease suppression.

References

Anderson, P. K., Cunningham, A. A., Patel, N. G., et al. (2004). Emerging infectious diseases of plants: pathogen pollution, climate change and agrotechnology drivers. *Trends in Ecology & Evolution*, 19(10), 535–544.

Hibino, H. (1996). Biology and epidemiology of rice viruses. *Annual Review of Phytopathology*, 34, 249–274.

Horowitz, A. R., Kontsedalov, S., Khasdan, V., & Ishaaya, I. (2020). Biotypes B and Q of Bemisia tabaci and their relevance to neonicotinoid and pyriproxyfen resistance. *Pest Management Science*, 76(7), 2284–2292.

Jones, R. A. C. (2021). Plant virus emergence and evolution: Origins, new encounter scenarios, factors driving emergence, effects of changing world conditions, and prospects for control. *Virus Research*, 304, 198508.

Navas-Castillo, J., Fiallo-Olivé, E., & Sánchez-Campos, S. (2011). Emerging virus diseases transmitted by whiteflies.

Annual Review of Phytopathology, 49, 219–248.

Ng, J. C. K., & Perry, K. L. (2004). Transmission of plant viruses by aphid vectors. *Molecular Plant Pathology*, 5(5), 505–511.

Power, A. G. (1992). Host plant dispersion, leafhopper movement, and virus transmission. *Ecological Entomology*, 17(1), 63–68.

Rotenberg, D., Jacobson, A. L., Schneweis, D. J., & Whitfield, A. E. (2015). Thrips transmission of tospoviruses. *Current Opinion in Virology*, 15, 80–89.

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Emerging Biopesticides and Botanicals in Sustainable Agriculture: Advances, Challenges, and Future Prospects

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The escalating concerns over environmental sustainability, pesticide resistance, and food safety have necessitated the exploration of biopesticides as viable alternatives to synthetic agrochemicals. Biopesticides—derived from natural sources like microorganisms, plant extracts, and biochemicals—offer a targeted, eco-friendly, and residue-free approach to pest management. This article explores the latest trends in biopesticide development, regulatory changes, technological innovations, and their growing applications in managing pests of field crops such as rice, wheat, cotton, and maize. Emphasis is placed on their integration within the framework of Integrated Pest Management (IPM) and the challenges and opportunities for their widespread adoption. Biopesticides and botanical pesticides are emerging as vital tools in achieving sustainable agriculture by offering effective, eco-friendly alternatives to synthetic chemical pesticides. These natural formulations, derived from microorganisms and plants, target specific pests while preserving ecological balance and human health. This research article provides a comprehensive review of microbial and botanical biopesticides, with a focus on Indian agriculture. It delves into their classifications, mechanisms of action, formulation advancements, market dynamics, challenges, and future outlook. Emphasis is laid on key agents such as *Bacillus thuringiensis*, *Trichoderma spp.*, and neem-based botanicals, along with graphical representation of trends and comparative efficacy. Despite significant progress, adoption is hindered by formulation stability, awareness gaps, and regulatory hurdles. Strategic integration into IPM systems and supportive policies can accelerate biopesticide deployment, enabling more resilient and sustainable crop production systems.

Keywords: Biopesticides, Botanicals, Bacillus thuringiensis, Neem, Sustainable agriculture, IPM, Pest control, India

Introduction

With growing global demand for sustainable agriculture, the overuse of chemical pesticides has led to increased pest resistance, environmental degradation, and concerns over human health. In this context, biopesticides have emerged as a promising alternative. Defined broadly, biopesticides include microbial pesticides (e.g., *Bacillus thuringiensis*), botanical extracts (e.g., neem oil), and biochemical pesticides (e.g., pheromones). Their specificity, biodegradability, and compatibility with natural enemies make them highly suitable for inclusion in IPM systems, especially in field crops. The agricultural sector has long depended on synthetic chemical pesticides to combat crop pests and ensure food security. However, their extensive and often unregulated usage has led to numerous adverse effects, including pest resistance, resurgence, environmental pollution, and health hazards. In response, the spotlight is now turning toward more sustainable alternatives—biopesticides and botanicals. These biologically derived pest control agents align with global objectives for sustainable development and integrated pest management (IPM). India, with its vast agroecological diversity and growing organic sector, offers significant potential for the adoption and development of biopesticides.

Materials and Methods

This article is based on a thorough review of secondary sources, including peer-reviewed journal articles, reports, and policy documents. Key sources include data and literature from Indian and global agricultural institutions such as IARI, MDPI's Agriculture journal, and reports on pesticide regulations. Quantitative data on biopesticide usage, market trends, and product types were collected and analyzed. Comparative tables and visual graphs were created using Python and matplotlib. The literature selection prioritized publications from the last decade, with historical references included to provide foundational insights.

Classification of Biopesticides: Biopesticides are generally grouped into three categories:

1. Microbial Biopesticides: Derived from bacteria, fungi, viruses, or protozoa.(Examples: *Bacillus thuringiensis, Beauveria bassiana, Metarhizium anisopliae,* nucleopolyhedroviruses *(NPVs.))*. These agents infect and kill specific pests while leaving beneficial insects unharmed.
2. Botanical Pesticides: Plant-derived compounds with insecticidal or repellent properties. (Examples: Neem *(Azadirachta indica),* Pyrethrum *(Chrysanthemum spp,),* Rotenone).These Act as antifeedants, repellents, or toxins to target pests.
3. Biochemical Pesticides: Naturally occurring substances that control pests by non-toxic mechanisms. (Examples: Insect pheromones, growth regulators, and kairomones, plant-based volatiles). These influence the pest's behavior or development rather than directly killing them.

Recent Trends in Biopesticide Development

1. Nanotechnology: Nanoparticles are used to enhance the stability, bioavailability, and controlled release of biopesticides. Nanoencapsulation improves persistence in field conditions and reduces application frequency.
2. Formulation Advancements: Nanotechnology-enhanced formulations for improved stability and efficacy. Controlled-release microencapsulation techniques.
3. Genomic and Metagenomic Approaches: Identification of novel insecticidal genes and metabolites. Engineering of microbial strains for enhanced bioactivity.
4. Regulatory Facilitation: Faster approval processes and supportive government policies in countries like India, USA, and Brazil. Inclusion of biopesticides under sustainable agriculture missions.
5. Smart Application Systems: Drone-based spraying, precision pest detection, and decision-support systems are revolutionizing the use of biopesticides.
6. Market Growth: The global biopesticide market is projected to exceed USD 10 billion by 2030, growing at a CAGR of over 13%.

Applications in Field Crops

Rice: (*Trichoderma harzianum* for sheath blight control, NPV & Neem oil sprays to manage leaf folders and stem borers.)

Maize: (Use of *Beauveria bassiana* against fall armyworm *(Spodoptera frugiperda*), Entomopathogenic viruses targeting maize borers.)

Wheat: *(Pseudomonas fluorescens* and *Bacillus subtilis* combat root rot and *Fusarium* diseases., Neem-based granules for termite control, Neem and garlic extracts deter aphids and other sap-sucking pests.)

Cotton: (*Bt* biopesticide formulations against bollworms, Use of pheromone traps to monitor and disrupt pink bollworm *Pectinophora gossypiella*, Pheromone traps and neem-based

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Fig 1. The three different categories of Biopesticides and some selected examples of each category

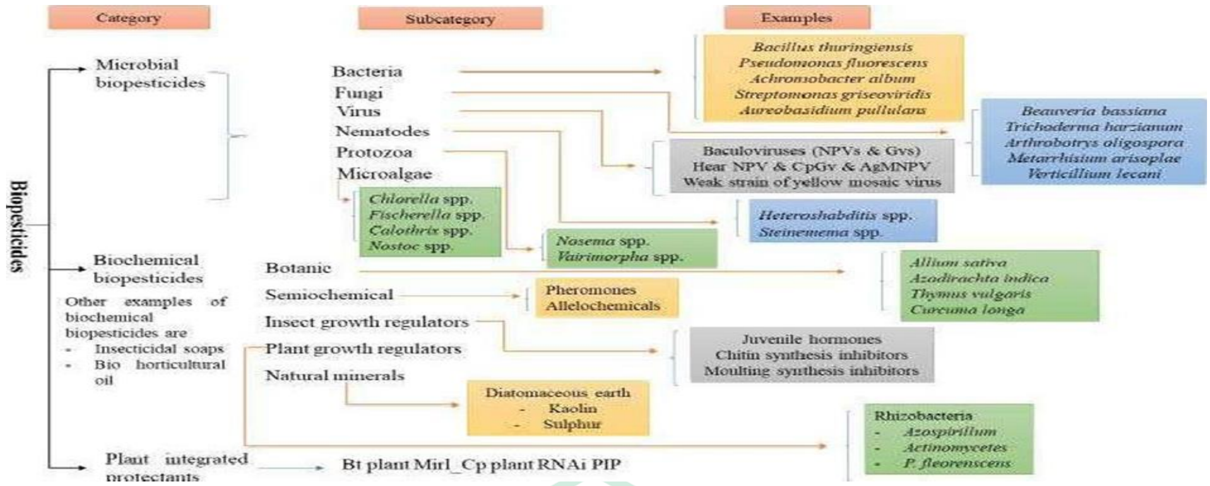

Table 1. Some of the plant's products are registered as biopesticides and their products with target organisms

Botanical Pesticides	Target Organism
Neem	Sucking and chewing insect (Aphids, Thrips, lepidopteran and coleopteran larvae such as apple codling moth, cotton bollworm, green leafhopper, etc.), nematodes and fungi (*Rhizoctonia solani*, *Fusarium oxysporum*, *Botrytis cinerea*, etc.)
Linalool and Limonene	Aphids, fleas, fire ants, mites, flies, house crickets, and paper wasps
Nicotine	Used as a fumigant against the soft-bodied insect pests
Pyrethrum	Mosquitoes, caterpillars, sawfly larvae, aphids, leafhoppers, house flies, *Culicoides variipennis*, ants, flour beetle, fleas, flies, cockroaches, and ticks
Rotenone	Aphids, beetles (bean leaf beetle, Colorado potato beetle, asparagus beetle, flea beetle, cucumber beetle, fleas, strawberry leaf beetles), and lice
Ryania	Caterpillars (European corn borer, corn earworm, and thrips)
Sabadilla	Harlequin bugs, squash bugs, leafhoppers, thrips, stink bugs, and caterpillars

Table 2. Bioinsecticides available in India.

Biocontrol Agents	Product Name	Against Pest
Bacillus thuringiensis subsp. laraelensis	Tacibio/Technar	Leipdopterous pests
B. thuringiensis subsp. Kurstaki	Bio-Bart/ Biolep/Halt/Taciobio-Btk	Leipdopterous pests
Baeuveria bassiana	Myco-Jaal/Biosoft/ATEC/Baeuveria/Larvo-Guard Biorin/Biolarves/Phalada 101B/Biogrubex/Biowonder/Veera/Bioguard/B io-power	Coffeo-berry borer, diamondback moth, thrips, grasshoppers, whiteflies, aphids, coding moth
Helicoverpa armigera NPV	Helicide/Helocide/Biovirus-H/Heligard/Virin-H	Cotton bollworm
Metarhizium anisopliae	ABTEC/Verticillium/Meta-Guard/Biomet/Biomagic/Meta/Biomet/Sun Agro Meta/Bio-Magic	Coleoptera and lepidoptera, termites, mosquitoes, leafhoppers, beetles, grubs
Pseudomonas fumosoroseus	Nemato-Guard	Whitefly
Pseudomonas lilacimus	Yorker/ABTEC/Paceilomyces Paecil Pacihit/R OM biomite/Bio-Nematon	Whitefly
Verticillium lecanii	Verisoft/Verticillium/Vert-Guard/Bioline/Biosappex/Versitile/Ecocil/Phal ada 107 V/Biovert Rich/ROM Verlac/ROM Gurbkill/Sun AgroVerti/Bio-Catch	Whitefly, green coffee bug, homopteran pests
Spodoptera litura NPV	Spodocide Spodoterin/Spodi-cide Biovirus-S	Spodoptera litura

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sprays help in managing pink bollworm and whiteflies.)

Regulatory and Market Trends: Governments across the globe are encouraging the use of biopesticides through regulatory support and certification standards. In India, biopesticides are regulated under the Insecticides Act, 1968, with a simplified registration process. Globally, the biopesticide market is witnessing significant growth, with projected values surpassing USD 10 billion by 2030. Key drivers include increasing organic farming, demand for eco-labeled produce, and government subsidies.

Integration with IPM : Biopesticides are most effective when integrated into a holistic IPM framework. Their use:

- Reduces pesticide load and residues.
- Enhances natural enemy populations.
- Slows down resistance development in pest populations.
- Can be rotated or combined with low-toxicity chemicals for synergistic effect.

Results and Discussion

Biopesticides are typically categorized into microbial, botanical, and biochemical agents. In India, microbial pesticides like *Bacillus thuringiensis* (*Bt*), *Trichoderma spp.*, and viral agents like Nucleopolyhedrovirus (NPV) dominate the market. Botanicals such as neem-based products are also widely adopted due to their low toxicity and biodegradability. The consumption of biopesticides in India has increased significantly over the last decade, particularly due to rising awareness of environmental safety and the push for organic farming.

Challenges and Limitations

- Formulation Stability: Biopesticides, particularly microbial ones, are sensitive to environmental conditions like UV radiation, temperature, and humidity. These factors reduce shelf-life and field efficacy.
- Limited Field Efficacy Data: Unlike chemical pesticides, biopesticides often lack extensive field trial data, making farmers skeptical about their performance
- Lack of Farmer Awareness: Many farmers, especially smallholders, lack knowledge of the correct usage, dosage, and timing of application.
- Weak Supply Chain Infrastructure: Storage and distribution systems are inadequate in many parts of India, limiting accessibility.
- Regulatory bottlenecks: Despite improvements, registration processes remain slow in many regions.
- Cost of Production: High production and formulation costs can make biopesticides expensive relative to their chemical counterparts.

Table 3. Common Microbial and Botanical Biopesticides in India

Biopesticide Type	Organism/Source	Target Pest/Crop
Bacterial	*Bacillus thuringiensis (Bt)*	Lepidopteran larvae (Cotton, Maize)
Fungal	*Trichoderma spp.*	Soil-borne plant pathogens
Viral	Nucleopolyhedrovirus (NPV)	Lepidopteran pests
Botanical	Neem (*Azadirachta indica*)	Aphids, Whiteflies, Caterpillars
Bacterial	*Pseudomonas fluorescens*	Fungal diseases (Rice, Pulses)

FUTURE PERSPECTIVES: Botanicals and biopesticides are likely to be an important part

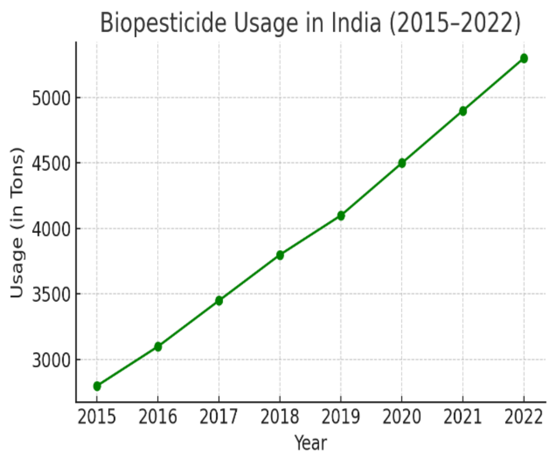

Figure 2. Growth of biopesticide usage in India from 2015 to 2022

of the Integrated Pest Management strategy for many crops especially vegetables and fruit crops in the near future. There will also be increased use in mosquito control. However, we need to develop effective strategies for using and pesticide in agriculture and health. Extension workers and farmers need to be educated on their use. The price of commercial products has to be competitive with chemical pesticides or alternatively the government has to provide subsidies for encouraging their use. The future of biopesticides lies in:

1. Precision agriculture integration: Drone-based applications and AI-powered pest forecasting.
2. Nano-formulations and Encapsulation: These technologies can improve stability and delivery.
3. Biotechnological innovations: Genetically enhanced biocontrol agents.
4. CRISPR and Genetic Engineering: Advanced techniques for microbial strain improvement can enhance efficacy.
5. Integration into IPM: Government policies now emphasize IPM systems that promote biopesticide use.
6. Digital Agriculture: Precision farming tools can optimize the application of biopesticides, enhancing their impact.
7. Public-Private Partnerships (PPP): Encouraging PPPs can accelerate R&D and field-level adaptation. To scale-up development, marketing, and distribution.
8. Policy support: Incentivizing production and usage through subsidies and training.

Conclusion:

Biopesticides represent a crucial tool in the transition toward sustainable, climate-resilient agriculture. Their eco-friendly nature, specificity, and compatibility with other control methods make them indispensable for modern field crop production. Overcoming current limitations through research, awareness, and infrastructure development will pave the way for their widespread acceptance and success. Biopesticides and botanicals offer promising alternatives to conventional chemical pesticides in India. Their environmentally safe profile, compatibility with organic and IPM practices, and ability to reduce chemical residues make them integral to sustainable agriculture. Despite notable challenges in formulation, awareness, and regulation, the future of biopesticides is optimistic. Strategic interventions, technological innovations, and supportive policies are essential to scale their adoption, ensuring healthier ecosystems and food systems.

References:

Anonymous 1991, 1992 Secretariat of Central Insecticide Board and Registration Committee, Directorate of Plant Protection, Quarantine and Storage, Faridabad, India.

Copping, L.G. & Menn, J.J. 2000, Biopesticides: a review of their action, applications and efficacy. *Pest Management Science.*, **56(8):** 651–676.

Devisetty, B.N. 1988, Pesticides formulations-opportunities and challenges, In *Pesticide Formulations and Application Systems*. 8th Volume, ASTM STP 980, p.46–64 (Eds D.A. Hovde and G.B. Bacsman American Society for Testing and Materials, 1916 Race Street, Philadelphia.

FAO., 2021, The State of the World's Biodiversity for Food and Agriculture.

Glare, T. et al. 2012. Have biopesticides come of age? Trends in Biotechnology, **30(5):** 250–258.

Kumar, S. & Singh, R., 2020, Biopesticides in Indian agriculture: Recent developments and challenges. *Indian Journal of Agricultural Sciences.,* **90(4):** 689–696.

Markets and Markets (2023). Biopesticides Market by Type, Source, Crop, Mode of Application – Global Forecast to 2030.

Mukhopadhyay, A.N., Shrestha S.M. and Mukerjee, P.K., 1992, Biological seed treatment for control of soil born plant pathogens. *FAO Plant Prot. Bull.* **40**(1-2): 21–30.

Parmar, B.S. and Ketkar, C.M. 1993, Commercialization. p.270–283 (Eds- N.S.

Randhawa and B.S. Parmar) *SPS Publication No. 4. In Neem Research and Development*. Society of Pesticide Science, India: 283 p.

Shah, M.A. et al. (2018). Nanopesticides: Future of Agricultural Pest Management. *Scientific Reports*, 8(1), 17462.

Chakraborty, N., et al. (2023). Biopesticide Consumption in India: Insights into the Current Trends. Agriculture, 13(557). https://doi.org/10.3390/agriculture13030557

Pavan, J.S., et al. (2024). Biopesticides in Indian Agriculture: Advances and Challenges. IJABR, SP-8(8), 936-943. https://doi.org/10.33545/26174693.2024.v8.i8Sm.1966

Rana, A., et al. (2022). Major Breakthroughs in Biopesticides in Recent Antiquity. International Journal of Health Sciences, 6(S1), 3733–3744. https://doi.org/10.53730/ijhs.v6nS1.5614

Parmar, B.S., & Devakumar, C. (1993). Botanical and Biopesticides. Society of Pesticide Science, India.

Mukhopadhay, A.N., et al. (1992). Use of Natural Antagonists in Plant Disease Control.

Keswani, C., et al. (2021). Biological Solutions for Sustainable Agriculture. Journal of Applied Microbiology.

Tripathi, A., et al. (2020). Integrated Pest Management and Biopesticide Use in India. Journal of Biocontrol.

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From Waste to Wealth: Value addition of Cashew Apple

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Introduction

The cashew tree (*Anacardium occidentale* L.), a native of Brazil, has become a commercially important crop in many tropical regions, especially India, Vietnam, and parts of Africa. While global attention predominantly focuses on the cashew nut, the cashew apple an accessory fruit—accounts for nearly 90% of the total fruit biomass and remains largely underutilized. In India alone, it is estimated that over 2 million tonnes of cashew apples are produced annually, yet less than 10% is effectively processed or preserved.

The cashew apple is a rich source of bioactive compounds. It contains up to 260–280 mg of ascorbic acid (vitamin C) per 100g nearly five times more than oranges. It also provides natural sugars (glucose, fructose), polyphenols, tannins, minerals like calcium and iron, and carotenoids, which contribute to its antioxidant potential. Despite its nutritional value, the high perishability (shelf life of 24–48 hours), astringent taste due to high tannin content, and limited consumer awareness hinder its widespread commercial exploitation.

Cashew Apple: An Underutilized Resource

The cashew apple is the fleshy peduncle attached to the cashew nut and is botanically classified as a pseudofruit. It constitutes the bulk of the cashew tree's fruit mass, often weighing 5–10 times more than the nut. In many cashew-growing regions of India, including Goa, Kerala, Tamil Nadu, and Odisha, cashew apples are harvested but largely discarded or allowed to ferment naturally due to the lack of organized collection and processing systems.

From a compositional standpoint, the cashew apple is highly nutritious and qualifies as a functional food. It contains:

Component	Content
Moisture	84.4-88.7 g
Protein	0.101-0.162 g
Fat	0.05-0.50 g
Carbohydrates	9.08-9.75 g
Fiber	0.4-1.0 g
Calcium	0.9-5.4 mg
Phosphorus	6.1-21.4 mg
Iron	0.19-0.71 mg
Carotene	0.03-0.742 mg
Thiamine	0.023-0.03 mg
Riboflavin	0.13-0.4 mg
Niacin	0.13-0.539 mg
Ascorbic Acid	146.6-372.0 mg

In spite of these rich bioactive compounds, the cashew apple remains highly underutilized. The main barriers include:

- **High perishability:** The fruit has a shelf life of only 1–2 days under ambient conditions, making storage and transport difficult.
- **Astringent taste:** Due to tannins and other phenolics, which reduce consumer acceptability in raw form.
- **Mechanical damage:** Soft texture leads to bruising during handling and harvest.
- **Lack of processing infrastructure:** Especially in rural and semi-urban areas where most cashew orchards are located.

Challenges in Cashew Apple Utilization

Despite its nutritional richness and industrial potential, the cashew apple remains one of the most underutilized agricultural by-products.

Several constraints biological, technical, economic, and infrastructural hinder its effective utilization and commercialization. Addressing these challenges is crucial to unlock its full value.

1. Perishability & Postharvest Losses

- **Short Shelf Life**: Cashew apple starts fermenting or spoiling within 24–48 hours post-harvest if not processed or refrigerated.
- **Transport Issues**: Its soft texture and high moisture content (85–90%) make it unsuitable for long-distance transit without special handling.
- **Loss Estimates**: Up to **90% of India's cashew apple production (over 2.5 million tonnes annually)** is wasted or underutilized.

2. Processing Constraints

- **Lack of Local Units**: Many cashew-growing areas, especially tribal belts in Maharashtra, Chhattisgarh, and Odisha, lack access to small-scale processing facilities.
- **Seasonality**: A short harvesting window (~March–May) results in processing bottlenecks.
- **Technical Gaps**: Limited adoption of optimized technologies for juice clarification, deastringency, and stabilization.

3. Astringency & Consumer Acceptance

- **High Tannin Content**: Cashew apple juice contains **1.5–2.5% tannins**, contributing to its puckering mouthfeel and low consumer acceptability in raw form.
- **Off-flavors**: Natural fermentation can introduce sulfurous or sweaty odors, especially in traditional processing of Feni or wines.

4. Market Development Issues

- **Low Awareness**: Consumers and even producers are unfamiliar with cashew apple-derived products like squash, vinegar, jam or syrup.
- **Branding Gaps**: Few brands have successfully positioned these products in urban health-conscious or export markets.
- **Pricing Volatility**: Lack of stable market prices for both raw apples and value-added products reduces entrepreneurial confidence.

5. Farmer Disengagement

- **Kernel-Centric Focus**: Farmers prioritize nut collection and drying, often discarding apples due to lack of incentives or time.
- **Labor Shortage**: Collecting and transporting apples increases labor cost without guaranteed returns.
- **Lack of Buy-Back Models**: Few FPOs or processors have formal apple procurement systems or contracts in place.

6. Policy & Institutional Limitations

- **No Dedicated Schemes**: While India has PMFME (Micro Food Processing) and MIDH (Mission on Integrated Development of Horticulture), no flagship scheme focuses on cashew apple value addition.
- **Standardization Issues**: Absence of clear FSSAI standards for many products (e.g., cashew apple wine, vinegar, and candy) hampers legal marketing and scaling.
- **Taxation & Excise:** Alcoholic products like cashew wine or Feni often face restrictive state taxes, licensing issues, and excise regulations.

7. Research-Industry Gap

- **Technology Transfer Bottlenecks**: Despite successful prototypes developed by institutes, there's a gap in licensing, dissemination, and commercialization.
- **Entrepreneurship Support**: Budding agro-processors struggle with bank credit, machinery access or FSSAI certifications.

Value-Added Products from Cashew Apple

The transformation of cashew apple from a perishable by-product into commercially viable value-added products has garnered increasing attention in recent years. Given its high sugar content, rich vitamin C levels, and favorable fermentation properties, cashew apple can be processed into a diverse range of products across food, beverage, pharmaceutical, and bio-industrial sectors. The development of these products not only enhances profitability but also contributes to sustainable agricultural practices by reducing postharvest losses.

a. Beverages

One of the most promising avenues for cashew apple utilization is in the preparation of non-alcoholic and alcoholic beverages.

i. Ready-to-Serve (RTS) Drinks and Juices: Cashew apple juice can be extracted, clarified and preserved to produce RTS beverages.Blending with other fruits such as pineapple, mango or lime can enhance sensory appeal and reduce astringency. Fortification with vitamin C or antioxidants further improves nutritional value.

Ready-to-Serve (RTS) Beverage

Harvesting of Cashew Apples
↓
Washing and Sorting
↓
Juice Extraction (crusher or pulper)
↓
Filtration (cloth or mesh filter)
↓
Blending with Sugar, Citric Acid, and Water
↓
Pasteurization (85–90°C for 15 minutes)
↓
Filling into Sterilized Bottles
↓
Cooling, Labelling, and Storage

ii. Squash and Syrups: High Total Soluble Solids (TSS) content in cashew apple (12–15° Brix) makes it suitable for squashes and syrups. Acidification and addition of preservatives like potassium metabisulfite (KMS) ensure longer shelf life.

Cashew Apple Squash Flowchart

Harvesting of Cashew Apples
↓
Washing and Juice Extraction
↓
Filtration and Clarification
↓
Addition of Sugar Syrup, Citric Acid, and Preservatives (e.g., KMS)
↓
Boiling and Concentration (up to ~45° Brix)
↓
Bottling into Clean, Dry Bottles
↓
Cooling, Labelling, and Storage

iii. Fermented Beverages:

Cashew Apple Wine: The sugar-rich juice is fermented with *Saccharomyces cerevisiae* to produce wine with alcohol content ranging from 8–12%. It is a traditional product in Goa and gaining popularity in other regions.

Cashew Apple Wine Flowchart

Harvesting of Cashew Apples
↓
Washing and Sorting
↓
Juice Extraction (Pulper or Crusher)
↓
Filtration/Clarification
↓
Pasteurization (85–90°C for 10–15 min)
↓
Cooling to Room Temperature (~25°C)
↓
Inoculation with Yeast (e.g., Saccharomyces cerevisiae)
↓
Primary Fermentation (5–7 days at 25–30°C)
↓
Racking and Secondary Fermentation (15–30 days)
↓
Filtration and Clarification (e.g., Bentonite)
↓
Ageing (Optional: 1–3 months)
↓
Bottling and Corking
↓
Labelling and Storage

Cashew Apple Cider and Vinegar: Through controlled fermentation, acetic acid bacteria convert ethanol to vinegar. The resulting product has culinary and preservative uses.

Cashew Apple Vinegar Flowchart

Harvesting of Cashew Apples
↓
Washing and Juice Extraction
↓
Pasteurization and Cooling
↓
Alcoholic Fermentation (Yeast: Saccharomyces cerevisiae)
↓
Racking and Filtration
↓
Acetic Acid Fermentation (Acetobacter spp.)
↓
Clarification and Pasteurization
↓
Bottling, Labelling, and Storage

b. Jams, Jellies, and Candies

Cashew apple pulp can be converted into shelf-stable semisolid and solid products:

Jam and Jelly: Requires adjustment of sugar-acid ratio and addition of pectin. Cooking under vacuum or open pan systems is used.

Cashew Apple Jam/Jelly Flowchart

Harvesting of Cashew Apples
↓
Washing and Pulp Extraction
↓
Filtration or Straining
↓
Cooking with Sugar and Citric Acid
↓
Addition of Pectin (optional for jelly)
↓
Boiling to Desired Consistency (65–68° Brix)
↓
Filling into Hot Sterilized Bottles/Jars
↓
Sealing, Cooling, Labelling, and Storage

Candied Cashew Apple: Sliced apple pieces are osmotically dehydrated in sugar syrup and dried to create a chewy product. These products cater to niche gourmet and confectionery markets.

Candied Cashew Apple Flowchart

Harvesting of Cashew Apples
↓
Washing and Slicing into Uniform Pieces
↓
Blanching (boiling water or steam)
↓
Soaking in Sugar Syrup (Gradual Concentration)
↓
Draining and Drying (Sun Drying / Hot Air Oven)
↓
Optional Coating (e.g., sugar powder)
↓
Packaging and Storage

c. Cashew Apple Powder

Drying cashew apple pulp into powder enables year-round use. Tray drying (60–70°C), spray drying, and freeze drying are commonly used.

Applications: The powder can be used as a natural flavor enhancer in drinks, bakery products, nutraceutical blends and infant foods. It is also rich in antioxidants and has prebiotic potential due to its polyphenol content.

Cashew Apple Powder Flowchart

Harvesting of Cashew Apples
↓
Washing and Pulp Extraction
↓
Filtration or Blending
↓
Drying (Tray Drying / Spray Drying / Freeze Drying)
↓
Grinding into Fine Powder
↓
Sieving and Packaging
↓
Storage in Moisture-Proof Containers

d. Animal Feed and Agro-Industrial Applications

Cashew apple pomace and waste pulp have significant utility in non-food applications:

Silage and Feed: Fermented or sun-dried apple residues can be incorporated into cattle feed, providing fiber and energy.

Cashew Apple-Based Cattle Feed/Silage Flowchart

Collection of Cashew Apple Residue (Pulp/Pomace)

↓

Chopping or Grinding (if needed)

↓

Mixing with Dry Matter Additives (e.g., wheat bran, molasses)

↓

Packing into Airtight Silage Bags or Pits

↓

Anaerobic Fermentation (15–30 days)

↓

Storage and Use as Livestock Feed

Composting: Residues are composted and used as organic fertilizer.

Enzyme Production: Microbial fermentation of cashew apple biomass is explored for producing cellulases, pectinases, and bioactive enzymes for industrial use.

Bioethanol from Cashew Apple Flowchart

Harvesting of Cashew Apples

↓

Washing and Juice Extraction

↓

Filtration and Pasteurization

↓

Cooling and Inoculation with Yeast (e.g., Saccharomyces cerevisiae)

↓

Alcoholic Fermentation (5–7 days)

↓

Distillation to Recover Ethanol

↓

Dehydration (Optional for Fuel Grade)

↓

Storage or Blending (Industrial Use / Biofuel)

e. Pharmaceutical and Functional Products

Due to its high antioxidant activity, cashew apple extract is used in developing functional foods and nutraceutical supplements. Its antimicrobial properties (due to polyphenols and tannins) show potential in natural preservative formulations and skin-care applications.

Conclusion

Cashew apple, though rich in nutrients and possessing immense potential, remains one of the most underutilized horticultural by-products due to challenges like high perishability, astringent taste caused by tannins and limited awareness about its value. However, through innovative value addition strategies, this neglected resource can be transformed into a wide range of products including juices, syrups, fermented beverages, candies, pickles and even animal feed or bio-fertilizers. By overcoming the existing barriers through improved processing techniques, better market linkages and increased awareness, cashew apple can emerge as a sustainable source of income for farmers and entrepreneurs, reduce postharvest losses, and contribute to the economy.

References

Abreu, F.A.P., Lima, L.C.O. & Gomes, J.P., 2005. *Post-harvest processing technology for cashew apple – A review*. Journal of Food Engineering.

Akinwale, T.O., 2000. Cashew apple juice: Its use in fortifying the nutritional quality of some tropical fruits. *European Food Research and Technology*, 211(3), pp.205–207.

Dedehou, E., 2016. *A review of cashew (Anacardium occidentale L.) apple: effects of processing techniques, properties and quality of juice*. African Journal of Biotechnology.

Jeyavishnu, K., Thulasidharan, D., Shereen, M.F. & Arumugam, A., 2021. *Increased revenue with high value-added products from cashew apple (Anacardium occidentale L.) – addressing global challenges. Food and Bioprocess Technology*, 14, pp.985–1012.

Pathare, M.A., Gaikwad, S.T., Pathare, M. & Nikhade, Y., 2020. *Utilization of cashew nut waste: Cashew apple and shell. International Journal of Chemical Studies*, 8(1), pp.2076–2078

Ponnuswami, V., Padmadevi, K. & Muthu Kumar, S., 2015. *Post-harvest strategies and value addition in cashew for combating malnutrition. Acta Horticulturae*, 1080, pp.345–352.

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From Farm to Foreign Markets: Challenges in Export of Fruits and Vegetables

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Introduction

India, the second-largest producer of fruits and vegetables globally, boasts immense potential in the global horticultural export market. Despite its natural advantages like diverse agro-climatic zones, a robust production base and improving logistics, the country contributes only about 1–2% to global horticultural trade. This article delves into the various challenges hampering the export of fruits and vegetables and offers insights into overcoming these hurdles.

Flowchart: From Farm to Foreign Market

1. Harvest from Orchard/Farm
2. Sorting & Grading at Packhouse
3. Precooling and Storage
4. Phytosanitary Certification & Lab Tests
5. Cold Chain Transport to Port
6. Customs and Port Clearance
7. Sea or Air Shipment
8. Import Inspection at Destination
9. Retail Distribution in Foreign Market

Major Export Challenges

- **At Farm Level:**
  i) Unscientific harvesting
  ii) Inadequate pesticide withdrawal period
  iii) Lack of export-specific cultivars
- **At Packhouse Level:**
  i) Manual grading ii) Poor hygiene iii) Non-standard packaging
- **Logistics:**
  i) Inadequate reefer container availability
  ii) Port delays and handling damage
- **Quality Compliance:**
  i) High rejection due to MRL violations
  ii) Lack of traceability and certification (GLOBAL G.A.P., ISO)
- **Policy Bottlenecks:**
  i) Delayed APEDA registration
  ii) High transaction cost
  iii) Limited air cargo slots for perishables

Challenges in Fruits and vegetables export

1. Perishability and Short Shelf Life:
Fruits and vegetables are highly perishable commodities, susceptible to rapid deterioration if not handled properly. This creates a major challenge in maintaining quality during long-distance transportation.

2. Inadequate Cold Chain and Infrastructure:
A well-developed cold chain is essential for preserving freshness. Unfortunately, India lacks sufficient refrigerated storage and transport facilities.

3. Stringent Quality and Safety Standards:
Export destinations like the EU, US, and Japan have strict Maximum Residue Limits (MRLs) and phytosanitary regulations. Indian produce often fails to meet these standards due to lack of awareness and improper pesticide use.

Common Compliance Issues: i) High pesticide residues ii) Improper documentation iii) Lack of traceability

4. Market Access and Non-Tariff Barriers:
Several fruits and vegetables face limited market access due to absence of export protocols or unresolved sanitary issues.

5. Inconsistent Grading and Packaging:
Indian exports suffer from inconsistent product quality, improper grading, and use of substandard packaging materials. This leads to damage during transit and reduced consumer confidence.

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Horticultural Export Performance: At a Glance

Parameter	2023–24 Statistics	Change from Previous Year
Total Horticultural Production	~352 million tonnes	↓0.9%
Fruit Production	112.6 million tonnes	↑2.3%
Vegetable Production	~205 million tonnes	Minor fluctuation
Total Fruits & Vegetables Export Value	US $ 3.7 billion	↑14%
Fresh Vegetables Export (Volume)	689,000 tonnes	↑20%
Onion Export (Apr–Feb 2023–24)	1.7 million tonnes worth US $ 468 million	↓ Compared to 2.5 Mt in 2022–23

Crop-wise Export Insights:

Crop	Origin States	Destination Countries	Key Import Requirements
Mango	Maharashtra, UP, Gujarat, Andhra Pradesh	USA, UK, Japan, UAE, EU	Vapour Heat Treatment (VHT), fruit fly-free certification, irradiation
Grapes	Maharashtra (Nashik), Karnataka	Netherlands, UK, EU, Russia	GLOBALG.A.P., residue compliance, cold chain traceability
Banana	Tamil Nadu, Maharashtra, Gujarat	UAE, Iran, Saudi Arabia, Russia	Crown rot-free, cold chain, uniform maturity
Pomegranate	Maharashtra, Gujarat	UAE, Netherlands, Saudi Arabia, Canada	Anthracnose-free, export grading, cold storage
Onion	Maharashtra, Gujarat, Karnataka	Bangladesh, Sri Lanka, UAE, Malaysia	Low moisture, fumigation, mesh packing
Dry Chilli	Andhra Pradesh, Telangana, Madhya Pradesh	Sri Lanka, Vietnam, China	Low aflatoxin, fungus-free, solar drying
Okra (Bhendi)	Gujarat, Maharashtra, Karnataka	UK, UAE, Germany	Cold chain, pesticide-free, small tender pods
Papaya	Tamil Nadu, Odisha, Gujarat	UK, Ireland, Bahrain	Latex-free harvest, non-bruised, firm flesh
Guava	Uttar Pradesh, Bihar, Maharashtra	Singapore, Middle East	Fly-free zones, grading, precooled storage
Kinnow	Punjab, Rajasthan	Middle East, Russia	Non-split fruits, pest-free skin, size uniformity
Litchi	Bihar, West Bengal, Jharkhand	UK, UAE, Canada	Sulphur-free, freshness retained, quick air transport
Apple	Himachal Pradesh, J&K	Gulf, SEA countries	MRL compliance, cold chain, firm and graded fruits
Pineapple	West Bengal, Kerala	Europe, Gulf	Cylindrical uniformity, non-fibrous, traceable batches
Dragon Fruit	Gujarat, West Bengal	UK, Bahrain, Netherlands	Phytosanitary certificate, exotic fruit protocols

Shelf Life of Common Exported Fruits and Vegetables

Crop	Average Shelf Life (Days)	Export Challenge
Mango	7-14	Ripening during transit
Grapes	20-30	Require cold chain from harvest
Tomato	5-10	High spoilage risk
Pomegranate	30-60	Sensitive to fungal infection
Banana	7-14	Ethylene-induced ripening
Papaya	4-7	High perishability and bruising
Litchi	5-7	Rapid browning and microbial decay
Green Beans	7-10	Sensitive to temperature fluctuations
Guava	5-8	Quick ripening, pest infestation

Import Requirements of Destination Countries for Horticultural Commodities

Destination Country	Commodity	Import Requirements	Relevant Authorities
USA	Mango	Vapor Heat Treatment (VHT); Pest-free certification; Treatment under APHIS supervision	USDA-APHIS, FDA
	Grapes	MRL compliance; Pest risk analysis; Must be from registered vineyards	USDA-APHIS, FDA
European Union (EU)	Grapes, Chilli, Okra	Strict MRL (pesticide) compliance; Traceability (e.g., GrapeNet for grapes); Phytosanitary certificate	DG SANTE, EFSA
	Mango, Pomegranate	Fruit fly-free certification; No irradiation allowed; Cold treatment protocol	DG SANTE, CPHR
United Arab Emirates	Banana, Mango, Onion	Phytosanitary certificate; No live insect/pest presence; Proper labelling and shelf life	UAE Ministry of Climate Change & Environment
Saudi Arabia	Onion, Tomato, Citrus	No residues above local MRL; Clean and pest-free produce; Certificate of origin	SFDA, Ministry of Environment, Water & Agriculture
Russia	Citrus, Apple	Phytosanitary certificate; No quarantine pests; Certificate of conformity	Rosselkhoznadzor
Canada	Mango, Litchi	Irradiation certificate; Quarantine pest control; Compliance with safe food for Canadians regulations	CFIA
Bangladesh	Onion, Potato, Fruits	Fumigation certificate; Plant quarantine clearance; Non-GMO declaration	Department of Agricultural Extension (DAE)
Nepal	Tomato, Guava	Phytosanitary certificate; Visual pest inspection; No specific residue limits	Department of Food Technology and Quality Control
Sri Lanka	Chilli, Banana	Pest-free certification; Quarantine clearance; Acceptable quality grades	Department of Agriculture, Sri Lanka
Malaysia	Mango, Banana	Must be from GAP-certified farms; No postharvest ethylene treatment; Phytosanitary certificate	FAMA, DOA Malaysia
Iran	Banana, Onion	Certificate of origin; Residue-free produce; Proper labelling and packing	Iran Veterinary Organization & Quarantine Dept.
UK	Grapes, Mango	MRL compliance as per UK/EU; Residue analysis reports; Pest-free confirmation	DEFRA, FSA
Oman	Papaya, Guava	Fresh produce certificate; Label with origin and handling conditions; Certificate of conformance	Ministry of Agriculture and Fisheries
Qatar	Papaya, Citrus	Hygiene certification; Phytosanitary certificate; Arabic/English bilingual labeling	Ministry of Public Health

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Selected Crops with Market Access Issues

Crop	Market Concern	Impact
Mango	Vapor heat treatment requirement	Limited to certain ports
Banana	Pest and quarantine concerns	Delayed market approvals
Chilli	Aflatoxin and pesticide limits	Rejection in EU markets
Drumstick	Pest infestation (fruit borer)	Limited export volumes
Okra	High pesticide residues	Frequent rejections in EU
Pineapple	Bromelain-induced bruising	Quality loss in transit
Onion	High moisture leads to rotting	Packaging and storage issues

Government Support for Boosting Horticulture Exports

Scheme / Initiative	Implementing Body	Support Provided	Target Beneficiaries
Agri Export Policy (AEP), 2018	Ministry of Commerce & Industry (MoCI)	- Cluster development - Infrastructure strengthening - Market linkages - Branding	Exporters, FPOs, SHGs, Agri Startups
APEDA (Agri & Processed Food Products Export Development Authority)	Ministry of Commerce & Industry	- Export promotion - Registration of exporters - Financial assistance for infrastructure	Exporters of fruits, vegetables, processed products
Transport and Marketing Assistance (TMA)	Ministry of Commerce & Industry	- Freight cost reimbursement for export by air/sea	Horticultural exporters to non-traditional markets
Operation Greens – TOP to TOTAL	Ministry of Food Processing Industries (MoFPI)	- 50% subsidy on transport and storage - Support for Tomato, Onion, Potato initially, now extended	Farmers, Aggregators, Logistics agencies
Mission for Integrated Development of Horticulture (MIDH)	Ministry of Agriculture	- Financial assistance for production, postharvest, and cold storage infrastructure	Farmers, FPOs, SHGs
PM Formalization of Micro Food Processing Enterprises (PM-FME)	MoFPI	- 35% subsidy on infrastructure, processing units - Branding and marketing support	Micro food enterprises, Self Help Groups
Export Facilitation through GrapeNet, BananaNet, HortiNet	APEDA	- Digital traceability and certification - Ensures export quality compliance	Farmers, Exporters
Plant Quarantine Infrastructure Development Scheme	Ministry of Agriculture	- Establishment of quarantine stations - Laboratory upgradation	Export inspection and certification agencies
Mega Food Parks & Agro-Processing Clusters	MoFPI	- Integrated value chain with cold storage, packaging, logistics, testing labs	Private investors, food processors, FPOs
District as Export Hub (DEH) Initiative	MoCI, in coordination with state departments	- Crop cluster identification - District-level export action plan - Market linkages	Local producers and exporters
One District One Product (ODOP)	Ministry of Commerce & Industry & State Govts	- Identifies unique agri products per district for promotion - Export branding	District-level producers and MSMEs
National Horticulture Board (NHB) Subsidies	NHB, MoA&FW	- Financial assistance for cold chain, packhouses, ripening chambers, marketing infrastructure	Entrepreneurs, FPOs, Corporates
Market Access Initiative (MAI)	Ministry of Commerce	- Assistance for product branding - Buyer-seller meets - International trade fairs	Export councils, trade bodies, exporters
RKVY-RAFTAAR	Ministry of Agriculture	- Agribusiness incubation - Infrastructure support for value chain	Startups, innovators, young agri-entrepreneurs
Krishi Udaan Scheme	Ministry of Civil Aviation	- Air cargo support for perishables from northeast, tribal, and hill regions	Agri exporters, farmers from remote areas
eNAM Integration with Export Portals	Ministry of Agriculture	- Linking of domestic markets with global buyers	FPOs, Mandis, Traders

Need of the Hour: i) Standardized packaging norms ii) Automated sorting and grading iii) Use of recyclable, breathable packaging

6. Limited Processing and Value Addition:
Processing technologies like dehydration, pulping, and freeze-drying are underutilized.

Opportunities: - Export of dried mango, jackfruit chips, tomato puree - Ready-to-eat and minimally processed products

7. Weak Linkages and Farmer Awareness:
Smallholders lack access to export markets due to fragmented supply chains and insufficient knowledge.

8. Financial and Policy Constraints:
Export procedures are often bureaucratic, and small exporters face high costs of certification and logistics.

Suggested Interventions: i) Subsidies for cold chain and certification ii) One-stop digital export portal iii) Strengthening Agri Export Zones (AEZs)

Conclusion

India is no longer just a producer of fruits and vegetables—it is emerging as a serious player in global agri-trade. However, the journey from farm to foreign supermarket is fraught with quality hurdles, compliance gaps, and logistical constraints. By focusing on crop-specific improvements, export infrastructure, and training for compliance, India can strengthen its position in the global horticultural map. With the right postharvest practices and export alignment, India's fields can truly feed the world.

References

1. APEDA (2024). Annual Agri Export Report.
2. National Horticulture Board (2023). Cold Chain Directory.
3. Ministry of Commerce and Industry, Government of India.
4. FAO. (2022). Postharvest Losses in Horticulture
5. APEDA Export Statistics (2023–24), Government of India
6. Ministry of Agriculture & Farmers Welfare, Government of India.
7. FAO Horticultural Outlook 2024

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Managing the Soil Weed Seed Bank: A Crucial Strategy for Sustainable Crop Production

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Introduction

In the context of sustainable agriculture, weeds pose a persistent challenge that impacts crop yield, quality, and economic viability. A critical yet often under-addressed aspect of weed ecology is the soil weed seed bank—a reserve of viable weed seeds present in the soil that serves as a primary source of future weed infestations. This underground reservoir includes freshly shed seeds as well as dormant seeds from past seasons, and in some cases, vegetative structures like rhizomes and tubers of perennial weeds.

Understanding and managing the weed seed bank is key to developing an integrated weed management (IWM) strategy. Not only does it help in reducing the weed pressure in subsequent cropping seasons, but it also minimizes the dependence on chemical herbicides, thereby promoting ecological and economic sustainability. According to Hossain & Begum (2016), effective management of the weed seed bank can significantly reduce the costs and environmental impact of weed control.

Dynamics of the Weed Seed Bank

1. Composition and Behavior

The weed seed bank is composed of both **transient seeds**, which survive for a short time, and **persistent seeds**, capable of surviving in the soil for decades. For instance, *Chenopodium album* (pigweed) and *Amaranthus retroflexus* (redroot pigweed) can remain viable for over 20 years, while species like *Kochia scoparia* require almost yearly replenishment.

Once in the soil, weed seeds face various fates: predation by insects and birds, decay due to microbial activity, lethal germination from deep burial, or dormancy triggered by environmental conditions. According to Menalled (2013), less than 10% of deposited weed seeds typically germinate, with the remainder lost to natural mortality factors.

2. Dormancy Mechanisms

Weed seed dormancy is a survival mechanism that ensures germination only under favorable conditions. **Primary dormancy** occurs right after seed dispersal, while **secondary dormancy** is induced or broken by environmental signals like light, temperature, oxygen, or biochemical cues. For example, seeds of *Avena fatua* (wild oat) exhibit dormancy regulated by seasonal temperature shifts, allowing germination predominantly in spring.

Some seeds also respond to chemicals like nitrate or smoke compounds, indicating available ecological niches for growth. Though intriguing, practical application of such techniques for mass germination (e.g., nitrate-induced germination) remains limited due to inconsistent results and high input costs.

Distribution and Assessment

1. Vertical Distribution

The vertical distribution of weed seeds in the soil varies with tillage. Plowing typically buries seeds deeper (4–6 inches), while no-till systems leave most seeds at or near the surface. This has major implications for germination and predation: surface seeds are more exposed to predators like beetles and birds, reducing seed bank persistence (Blubaugh & Kaplan, 2015).

2. Evaluating the Seed Bank

A practical method to assess the seed bank involves soil sampling and germination trials. Soil is collected in early spring, kept moist, and monitored for seedling emergence. This gives farmers a preview of potential weed problems, aiding in planning for timely interventions (Davis, 2004).

Strategies for Seed Bank Management

1. Reducing Seed Inputs

Preventing weeds from reaching maturity and shedding seeds is the most effective long-term strategy. Timely weeding, use of cover crops, and competitive crop varieties can significantly cut down seed rain into the soil.

2. Hand weeding:

Hand weeding is typically performed during the early stages of crop growth when weeds are still young. Removing weeds at this stage prevents them from maturing and producing seeds, thereby directly reducing the number of seeds that can replenish the seed bank. Repeated and timely hand weeding can drastically decrease the contribution of annual weeds to the seed bank.

2. Herbicide Application

While chemical herbicides are effective, over-reliance can lead to resistance and environmental issues. Pre-harvest applications of herbicides can reduce seed viability but must be timed before seed maturity.

3. Crop Rotation and Competition

Incorporating perennial crops or diverse crop rotations disrupts weed life cycles and reduces the dominance of specific weed species. Crops that grow quickly and establish dense canopies outcompete weeds, reducing seed production.

4. Mechanical and Cultural Methods

- **Tillage:** Inverts the soil, burying seeds too deep to germinate. However, frequent tillage can also stimulate dormancy break due to light exposure.
- **No-Till with Mulching:** Encourages seed predation and alters soil microclimate, suppressing germination of shallow-rooted weeds.

5. Fertilizer Management

Proper timing and placement of fertilizers such as banding nitrogen at planting can give crops a competitive advantage over weeds. Broadcast fertilization often benefits weeds more than crops, contributing to seed bank buildup.

6. Biological Control

Natural enemies like seed-feeding insects, soil pathogens, and allelopathic residues from previous crops (e.g., rye, clover) can suppress seed viability and germination. Encouraging such biocontrol agents is especially useful in organic systems.

Conclusion

The soil weed seed bank is both a challenge and an opportunity in sustainable crop production. By focusing on strategies that prevent seed input and enhance seed loss through germination or predation, farmers can significantly reduce future weed infestations. Integration of cultural, mechanical, biological, and chemical methods offers a robust and eco-friendly approach. With increasing concerns over herbicide resistance and environmental impact, managing the weed seed bank must become a central component of modern weed management strategies.

References

1. Hossain, M.M. & Begum, M. (2016). *Soil weed seed bank: Importance and management for sustainable crop production – A Review*. Journal of the Bangladesh Agricultural University, 13(2), 221–228.
2. Menalled, F.D. (2013). *Manage the Weed Seed Bank—Minimize Deposits and Maximize Withdrawals.* extension.org
3. Gulden, R.H., & Shirtliffe, S.J. (2009). *Weed Seed Banks: Biology and Management.* Prairie Soils & Crops Journal, 2: 46-52.

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Green Manuring: A Sustainable Strategy for Enhancing Soil Health and Fertility

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Introduction

In the context of sustainable agriculture, the health and fertility of soil play a pivotal role in determining long-term agricultural productivity and environmental conservation. Traditional chemical-based farming practices have often led to soil degradation, nutrient imbalance, and environmental pollution. Green manuring, an age-old agroecological practice, has recently garnered significant attention for its potential to rejuvenate soils naturally and sustainably. It involves growing specific crops, primarily legumes, and incorporating them into the soil while still green to enhance organic matter and nutrient content.

Concept and Classification of Green Manuring

Green manuring refers to the cultivation of green plants, either in situ or collected as green foliage, which are later incorporated into the soil to boost fertility. It can be categorized into two primary types:

1. **In-situ Green Manuring**: This involves cultivating leguminous crops such as **Sunnhemp (Crotalaria juncea)**, **Dhaincha (Sesbania aculeata)**, **Mung (Vigna radiata)**, **Cowpea (Vigna unguiculata)**, and incorporating them at the site itself after 6–8 weeks of growth (Prajapati et al., 2023; Alam et al., 2022).
2. **Green Leaf Manuring**: This method utilizes the green leaves and tender branches from trees and shrubs such as **Gliricidia**, **Neem**, **Subabul**, and **Karanj**, collected from bunds or forests and incorporated into the soil (Alam et al., 2022).

These green manures serve multiple agronomic roles—cover crops reduce erosion, smother crops suppress weeds, and nitrogen-fixing legumes enhance soil nutrient content.

Mechanisms of Soil Fertility Improvement

Green manuring enhances soil health through the following mechanisms:

- **Nutrient Enrichment and Recycling**: Green manure crops absorb macro and micronutrients like nitrogen (N), phosphorus (P), potassium (K), iron (Fe), and zinc (Zn) from the deeper soil layers. Upon decomposition, these nutrients become available for subsequent crops (Prajapati et al., 2023).
- **Biological Nitrogen Fixation**: Legumes form symbiotic associations with rhizobia bacteria, converting atmospheric nitrogen into ammonia—an accessible form for crops. Sunnhemp and Sesbania, for example, can fix up to **134 kg/ha of nitrogen** (Alam et al., 2022).
- **Improved Soil Structure and Water Retention**: The fibrous roots of green manure crops loosen compacted soils, enhance aeration, and improve water retention. This reduces runoff and erosion while facilitating better root penetration for subsequent crops (Prajapati et al., 2023).
- **Microbial Stimulation and Organic Matter Addition**: The decomposed plant material acts as a food source for soil microbes, increasing microbial diversity and accelerating nutrient cycling (Alam et al., 2022).

Agronomic Benefits and Crop Synergy

The integration of green manures offers numerous agronomic advantages:

- **Enhanced Crop Yield**: Studies have shown improved yields in rice, sugarcane, and millets when green manuring is integrated into the cropping system (Alam et al., 2022). The practice supports organic matter accumulation and nutrient synchronization with crop demand.
- **Synergistic Use with Fertilizers**: Application of phosphatic fertilizers in legume green manure crops enhances phosphorus uptake efficiency, complementing nitrogen fixation and improving overall nutrient use efficiency (Prajapati et al., 2023).
- **Pest and Disease Management**: Some green manure species act as break crops, disrupting the life cycle of pests and pathogens. Brassica plants once incorporated into soil as green manures have recently been shown to have biofumigant properties and have the potential of controlling plant-parasitic nematodes.
- **Climate Resilience and Carbon Sequestration**: Green manuring enhances soil carbon content, playing a role in climate change mitigation. It also buffers crops against abiotic stress by improving soil moisture and thermal regulation.

Constraints and Considerations

Despite its potential, several constraints hinder the widespread adoption of green manuring:

- **Time and Space Competition**: In intensive cropping systems, dedicating 6–8 weeks for green manure growth may be seen as economically nonviable due to opportunity cost (Alam et al., 2022).
- **Moisture Dependency**: In rainfed regions, unreliable precipitation affects the biomass yield and decomposition rate of green manure crops, reducing their effectiveness.
- **Variable Efficacy Across Soils**: The impact of green manuring varies with soil type, crop species, and climate. In alkaline soils, it can reduce pH through the production of organic acids like humic and acetic acid, but the benefits are not uniform.
- **Farmer Awareness and Extension Gaps**: Limited awareness, lack of institutional support, and absence of immediate visible benefits make farmers hesitant to adopt the practice.

Conclusion

Green manuring represents a time-tested yet forward-looking solution to the modern crisis of soil degradation and declining productivity. By integrating leguminous and biomass-rich crops into cropping systems, farmers can harness natural processes to boost soil fertility, reduce input costs, and build climate resilience. While challenges remain in terms of adoption, the ecological and economic rationale for green manuring is compelling. As sustainable agriculture becomes a global priority, green manuring must be embedded into policy frameworks and farmer practices to achieve soil regeneration and long-term food security.

References

1. Prajapati, S.K., Dayal, P., Kumar, V., & Gairola, A. (2023). *Green Manuring: A Sustainable Path to Improve Soil Health and Fertility*. AgriSustain-An International Journal, 01(2), 24-33. https://journals.rdagriculture.in
2. Alam, M.S., Patel, J.N., Pachauri, R.K., Singh, S., & Tiwari, H. (2022). *Green Manuring*. Sunshine Agriculture e-Newsletter, 2(6), 4-6. https://www.researchgate.net/publication/361562045

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Wheat cultivation through resource conservation planting techniques

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Rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L. emend Fiori & Paol.) cropping system is a prime system occupies about 18 M ha in Asia, of which 13.5 M ha are in Indo-Gangetic Plains (IGP). In addition, a sizeable rice–wheat system area (1.06 M ha) exists in Kymore Plateau and Satpura hills agro-climatic zone of Madhya Pradesh outside the Indian IGP. Wheat is the most traded crop of the world and, next to rice as a vital source of calories, has higher protein content than other major cereals. In the last century, wheat production was revolutionized in the world with the introduction of dwarfing gene 'Norin 10' identified by Dr. Gonziro Inazuka from Norin Experiment Station, Japan and Dr. Norman E. Borlaug incorporated in wheat. In India, a noteworthy increase in productivity of wheat has been achieved during Green Revolution Era due to introduction of high yielding short statured varieties, increased use of chemical fertilizers, better irrigation facilities, improved weed and pest management measures, etc. After the green revolution era, the total factor productivity is declining and farmers have to apply more inputs to acquire the same yield. These may be due to conventional agriculture practices which involve intensive mining of natural resources and continuous degradation of natural resources. Other key reason for low wheat productivity is late planting. Many farmers grow late-maturing, fine-grained basmati rice varieties and the long turnaround time often reflects burning of previous crop residues, traditional crop establishment method, too wet or too dry soil moisture problems and unavailability of mechanical power for ploughing at the sowing time, causing late planting of wheat. There is an average yield loss 1.7% per day, when sown beyond 25 November due to high temperature above 30ºC at grain filling stage which influence final grain weight by reducing the duration of grain filling, due to the restraint of photosynthesis process and by inhibition of starch synthesis in the endosperm. This prompted to adopt alternative resource conservation planting techniques for wheat, which could enhance yield, conserve natural resources and minimize environmental pollution.

What are alternative resource conservation planting techniques for wheat?

Zero-till drill, rotary till drill, minimum tillage and bed planting come under the alternative resource conservation techniques for wheat planting which are very useful for conserving natural resources, reducing environmental pollution and improving productivity.

Cultivation practices

Field preparation and sowing

Zero-till drill: Zero-till drill is the direct placement of seed and fertilizers into an untilled seedbed by the help of a specially-designed machine. Research on zero tillage (ZT) for wheat in India started almost three decades ago with the following key events:

1970: Start of zero tillage research but lack of suitable planting machineries and weed management problem.

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1991: First prototype of the Indian ZT seed drill developed by GBPUA&T, Pantnagar.

1997: Improved ZT drill by private manufacturer.

Early 20th Century: Happy Seeder developed by the Dept. of Farm Power and Machinery of Punjab Agricultural University, Ludhiana.

Where combine harvesting is being popular, rice crop should be harvest from 12-15 cm height from the surface, crop residue should not burn and spot application of glyphosate on green weeds. Before the sowing, crop residue spread uniformly over the field. 'Happy Seeder' machine can drill wheat in the presence of crop residue under zero-till condition (Fig. 1 & 2). Seeder should be clean and calibrate prior to sowing. In manually rice harvested field, there is no previous crop residue so simple zero-till machine like Pantnagar zero-till ferti-seed drill can be used for direct drilling of wheat.

Fig. 1. Sowing of wheat by "Happy Seeder"

Fig. 2. Zero-tillage wheat with rice residue

Rotary till drill: The combination of rotary tiller with seed-cum-fertilizer drill and a light planker allows soil preparation with placement of seed and fertilizers and planking the soil in single operation (Fig. 3 & 4).

Fig. 3. Sowing of wheat by rotory till drill

Fig. 4. Wheat crop sown by rotory till drill

In manually-harvested rice field, direct drilling of wheat crop along with fertilizer placement and planking the field in single pass can be done by rotary till drill. But in combine harvested rice field, the machine can be used after removal of loose rice straw. Straw baler machine can be used for straw removal from field instead straw burning. Straw burning is an environmental enemy process. Farmers can trade rice straw and make money. The rice straw can be utilized by paper industry for paper production, dairy industry for fodder, mashroom industry for mashroom production, packaging industry for goods packaging, sugar industry for electricity and for organic manure production.

Minimum till drill: In conventional practice, there are 6 to 10 tractor operations to prepare the seed bed but in minimum till drill, there is minimum soil manipulation necessary for successful crop production. Tractor operations can be reduced from 6 to 10 to 2 to 3 operations.

There is minimum soil disturbance which is necessary for successful crop production. In manually-harvested rice field, one pass of cultivator followed by one pass of rotavator is sufficient to pulverized soil for successful crop production. In combine- harvested rice field, loose rice residue is incorporated by one pass of grass cuter machine followed by one pass of cultivator and rotavator, respectively are satisfactory to pulverized seedbed.

Bed planting: In this technology, after land preparation all three activities viz. bed formation, placement of fertilizers and seed are done in single pass.

In manually-harvested rice field, land preparation is done by one pass of cultivator followed by one pass of rotavator. In combine-harvested rice field, loose rice residue is incorporated by one pass of grass cuter machine followed by one pass of cultivator and rotavator, respectively are sufficient for land preparation. After achieving the well till seedbed, bed planter is done all three activities viz. bed formation, placement of fertilizers and seed in single pass (Fig. 5 & 6).

Seed rate and seed treatment

Seed rate of wheat is 80-100 kg/ha under resource conservation practices. In case of bed planting, seed rate may be reduced to 75 kg/ha. To protect the crop from seed- and soil-borne diseases, it is essential to treat the seed with fungicides *viz.* vitavax 75 wp @ 2.5 g/kg, Carbendazim (Bavistin 50 wp) @ 2.5 g/kg or tebuconazole (Raxil 2 DS) @ 2.5 g/kg seed.

Weed management:

The critical period of crop-weed competition is 30-45 days after sowing. Weeds compete with wheat for nutrients, soil moisture, sunlight and space when they are limiting, resulting in reduced yield, lower grain quality and increased production costs. Upto 30% mean loss in wheat yield by uncontrolled weeds and remove 20-90 kg nitrogen/ha, 2-13 kg phosphorus/ha and 28-54 kg potassium/ha from soil. A mixed flora of broad-leaved, grasses and cyperaceous weeds grows with wheat under different agro-climatic conditions. The most common weed species are given in Table 1.

Table 1. Common weed flora of wheat crop

Grassy weeds	Cyperaceous	Broadleaf
Phalaris minor (little canary grass), *Avena fatua* (wild oats), *Cynodon dactylon* (Bermuda grass), *Polypogon monospliensis* (foxtail), *Poa annua* (annual meadow grass),	*Cyprus rotundus* (purple nutsedge), *Cyprus esculentus* (yellow nutsedge)	*Chenopodium album* (lamb's quarters), *Rumex retroflex* and *R. dentatus* (golden dock), *Convolvulus arvensis* (field bind), *Melilotus indica* (sweet clover), *Melilotus alba* (white clover), *Medicago hispida* (Toothed bur clover), *Vicia sativa* (wild vetch), *Portulaca oleracea* (Pigweed), *Anagallis arvensis* (red chickweed)

Hand-weeding with a *khurpi* at 20-25 days after sowing is a conventional approach to manage weeds. Due to increasing nuclear families, expensive and shortage of farm labour, this approach is now restricted to small and marginal farmers. Also it is difficult to identify *Phalaris minor* and *Avena fatua* in early stage of growth from wheat seedlings. Chemical approach is effective and affordable for weed management. A pre-emergence of pendimethalin in 400-500 litres/ha of water within 3 days after sowing (DAS) provides a broad-spectrum control of weeds in wheat. However, post-emergence application of Mesosulfuron methyl 3% +

iodosulfuron methyl Sodium 0.6% or Clodinafop-propargyl + Metsulfuron or Sulphosulfuron 75% WG + Metsulfuron 5% WG etc. is necessary for effective control of weeds at 20-25 DAS.

There is poor efficacy of pre-emergence herbicide in zero tillage with rice residue retention due to presence of straw on surface results less contact between herbicide and land surface however, increased water volumes up to 600 to 800 liters/ha or application of pre-emergence herbicide just before a light irrigation through sprinkler which is necessary for uniform germination might be increase efficacy.

The adoption of zero tillage for wheat planting is emerging as a novel tool in weed management. Zero-till technology is an effective tool for managing P. minor, possibly due to early sowing in October as P. minor germinates at a temperature of 17-180C, which usually prevails in the middle of November and 6-8 t/ha of rice straw as a mulch reduces emergence of P. minor and other weeds.

Fertilizer management

The general N+P2O5+K2O (kg/ha) recommendations for wheat are 120+60+40, respectively in Madhya Pradesh. Half dose of nitrogen should be applied as basal and remaining half dose should be top-dressed at first irrigation. But in zero tillage with rice residue retention, 70% of nitrogen should be drill by happy seeder along with seed at different depth and remaining 30% of nitrogen should be top-dressed at flowering stage. Higher basal dose of nitrogen should be applied in zero tillage with rice residue retention due to broadcasting nitrogen onto the residue-covered surface is an inefficient method of top-dressing because there is less contact between nitrogenous fertilizer and land surface due to residue and potential for immobilization by surface residues and volatilization losses of nitrogen.

Water management

Wheat requires about 300-400 cm of irrigation water, depending upon various factor viz. climatic, edaphic and nature of variety. Water should be applied at critical stages for potential yield production. A light irrigation through sprinkler should be applied after the sowing for uniform germination. Crown-root initiation (21 DAS), late tillering (42 DAS), late jointing (60 DAS), flowering (80 DAS), milk (95 DAS) and dough (115 DAS) are the six critical stages for irrigation. The number of irrigation to be given on the basis of availability of water is given in Table 2.

Table 2. Number of irrigations based on the availability of water

No. of irrigation available	Critical stages
1	Crown-root initiation
2	Crown-root initiation + Late jointing
3	Crown-root initiation + Late jointing + Milk
4	Crown-root initiation + Late tillering + Flowering + Milk
5	Crown-root initiation + Late tillering + Late jointing + Flowering + Milk
6	All six critical stages

Remaining practices like plant protection, harvesting and threshing operations are similar to conventional planting of wheat. Need based plant protection may be taken up.

Some facts about resource conservation techniques for planting

Residue burning: In conventional agriculture, residue burning is a common practice for taking up rabi crop wheat where combine harvesting is being popular. However it is destructive in respect to environment, soil health and crop productivity. Burning practices of crop residues in rice-wheat rotation system adopted by farmers of Punjab and Haryana cause severe smog in the months of October-November in Delhi.

Energy use: Conventional planting consumes more energy, time and fuel than conservation planting techniques. Per liter of diesel burnt produces around 2.5 kg CO2.

Rodents: Farmers often complain regarding rodent problem in zero-till fields due to heavy load of crop residues which provide shelter in the field and thus encourages rat growth. Zinc phosphide is the most commonly used rotenticide bait for the management of rodents.

Tractor: Machinery for resource conservation techniques like happy seeder needs 45-50 HP tractors but maximum farmers having the tractors of 35 HP. So it is a major constraint to adopt resource conservation techniques.

Trust area

There is problem of perennial weeds specially Cynodon dactylon which is not manage by the selective as well as non-selective herbicides in zero-till farming. In zero-till farming, there is need to quantify the dose of fertilizers in initial transition period of 2-3 years and after the 3-4 years of zero-till farming as well because crop residue use as mulch on soil surface which increases soil organic carbon and soil organic carbon is the store house of nutrients. There is scope to develop light weight machinery for resource conservation techniques which will not require high HP tractors. There is need to aware the farmers about the payoffs of resource conservation techniques by ‘On Farm Trial’.

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Precision Farming: Transforming the Future of Agriculture

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Agriculture is the backbone of our country and economy, which accounts for almost 18.2 per cent of GDP and employs 42.3 per cent of the population. To meet the forthcoming demand and challenge, we have to divert towards new technologies, for revolutionizing our agricultural productivity. It is essential to develop eco-friendly technologies for maintaining crop productivity. Since long, it has been recognized that crops and soils are not uniform within a given field. Over the last decade, technical methods have been developed to utilize modern electronics to respond to field variability. Such methods are known as spatially variable crop production, geographic positioning system (GPS) based agriculture, site-specific and precision farming. The concept of Precision Agriculture avails the recent developments in sensors, green-house and protected agriculture structures. The time has now arrived to exploit all the modern tools available by bringing information technology and agricultural science together for improved economic and environmentally sustainable crop production.

Keywords: Site Specific Farming; GPS; GIS; VRT; Remote sensing; Controlled Traffic Farming

Introduction

Precision Farming or precision agriculture is defined as information and technology based farm management system to identify, analyze and manage variability within fields for optimum productivity, profitability, sustainability and protection of the land resource by minimizing the production costs. Professor Pierre C. Robert who is considered as the father of precision farming defined precision farming as precision agriculture is not just the injection of new technologies but it is rather an information revolution made possible by new technologies that result in a higher level, a more precise farm management system. Precision Agriculture is an integrated crop management system that attempts to match the kind and amount of inputs with the actual crop needs for small areas within a farm field. This goal is not new, but new technologies now available allow the concept of precision agriculture to be realized in a practical production setting. In this mode of farming, new information technologies can be used to make better decisions about many aspects of crop production. Precision farming is also referred as **Site Specific Farming (SSF), Smart Farming, GPS based farming**. It is sometimes known as **VRT (Variable Rate Technology)** and **Site Specific Agriculture**.

Need of Precision Farming

- To develop a methodology for **identifying the causes of within field variation** in crop performance.
- To develop **practical guidelines** required to implement precision farming technology to achieve best management.
- To explore the possibility of **using remote-sensing methods and GIS** to enable management decisions to be made in real time during the growth of the crop
- To determine the potential **economic and environmental benefits** of using precision farming technology in cropping system.

Importance of Precision Farming

- Reduction in cost of cultivation due to site-specific crop management practices
- Increase in production efficiency of inputs due to site specific management

- Reduction in chemical doses through variable rate application technologies
- Reduction in application of inputs, especially N fertilizer thus reducing nitrate oxides to the atmosphere and environmental pollution
- Reduced erosion, runoff and sedimentation of water bodies due to proper checks and balances
- Helps in implementing spatially-varied farm operations like tillage, seeding, harvesting and so on
- Performance of improved varieties and adoption of plant breeding programs
- Used for detection of nutrients and moisture loss
- Used for on-farm testing of agronomic practices to evaluate alternative management practices

Components or Technologies of Precision Farming

1. Global Positioning System (GPS): GPS is a navigation system based on a network of satellites that helps users to record positional information (latitude, longitude and elevation) with an accuracy of between 100 and 0.01 m. GPS allows precise mapping of the farms and together with appropriate software informs the farmer about the status of his crop and which part of the farm requires what input such as seeds, fertilizers, pesticides, herbicides and irrigation water etc.

2. Differential Global Positioning System (DGPS): A method to improve the accuracy of GPS that uses pseudo range errors measured at a known location to improve the measurements made by other GPS receivers within the same general geographic area.

3. Geographic Information System (GIS): Geographic Information System (GIS) is an important system which includes organised collection of computer hardware, software, geographic data and personal designed to efficiently captured, stored, update, manipulate, analyse and display all forms of geographically referenced information.

4. Grid Sampling: It is a method of breaking a field into grids of about 0.5-5 hectares. Sampling soil within the grids is useful to determine the appropriate rate of application of fertilizers. Several samples are taken from each grid, mixed and sent to the laboratory for analysis.

5. Variable Rate Technology (VRT): The existing field machinery with added Electronic Control Unit (ECU) and on board GPS can full-fill the variable rate requirement of input. Spray booms, the Spinning disc applicator with ECU and GPS have been used effectively for patch spraying. During the creation of nutrient requirement map for VRT, profit maximizing fertilizer rate should be considered more rather than yield maximizing fertilizer rate.

6. Remote Sensing: These are generally categories of aerial or satellite sensors. They can indicate variations in the colours of the field that corresponds to changes in soil type, crop development, field boundaries, roads, water, etc. Arial and satellite imagery can be processed to provide vegetative indices, which reflect the health of the plant.

7. Proximate Sensors: These sensors can be used to measure soil parameters such as N status and soil pH) and crop properties as the sensor attached tractor passes over the field.

8. Precision irrigation systems: Recent developments are being released for commercial use in sprinkler irrigation by controlling the irrigation machines motion with GPS based controllers. Wireless communication and sensor technologies are being developed to monitor soil and ambient conditions, along with operation parameters of the irrigation machines (i.e. flow and pressure) to achieve higher water use efficiency.

9. Precision farming on arable land: The use of precision agriculture techniques on arable land is the most widely used and most advanced amongst farmers. CTF (Controlled Traffic Farming) is a whole farm approach that aims at avoiding unnecessary crop damage and soil compaction by heavy machinery, reducing costs imposed by standard methods. Controlled traffic methods involve confining all field vehicles to the minimal area of permanent traffic lanes with the aid of decision support systems. Another important application of precision agriculture in arable land is to optimize the use of fertilizers especially, Nitrogen, Phosphorus and Potassium.

10. Yield Monitoring and Yield Mapping: Yield monitoring: Yield monitors are crop yield measuring devices installed in harvesting equipment. The yield data from the monitor is recorded and stored at regular interval along with positional data received from the GIS unit. Yield mapping: Mapping of yield and correlation of that map with the spatial and temporal variability of different agronomic parameters helps in development of next season crop management strategy.

Future Prospects

Opportunities will continue for Precision Agriculture studies. Tools will become available to apply chemicals, fertilizers, tillage, and seed differentially to a field and collect the yield or plant biomass by position across the field. Remote sensing technology will allow us to observe variation within a field throughout the growing season relative to the imposed management changes. Monitoring equipment exists for capturing the surface water and groundwater samples needed to quantify the environmental impact through surface runoff or leaching. The technology exists to capture the volatilization of nitrogen or pesticides from the field into the atmosphere from modified practices. The future direction of agriculture will depend upon the research community's ability to conduct this type of study, with confidence from the environmental and producer communities that changes will benefit the environment and increase the efficiency of agricultural production.

Conclusion

Precision farming has the scope to utilize the resources effectively at the right time in the right place and the potential to transition to advanced modern agriculture in order to achieve long-term sustainability in agriculture. It gives farmers the ability to use crop inputs more efficiently including fertilizers, pesticides, tillage and irrigation water. More effective use of inputs means greater crop yield and quality, without polluting the environment. However, it has proven difficult to determine the cost benefits of Precision Agriculture management. At present, many of the technologies used are in their infancy, and pricing of equipment and services is hard to pin down. This can make our current economic statements about a particular technology dated. Precision Agriculture can address both economic and environmental issues that surround production agriculture today. In view of the pressing necessity of today, there should be a concerted effort to leverage new technical inputs to stop the migration of people from rural to urban areas and make the 'Green Revolution' into an 'Evergreen Revolution'.

References

1. Press Information Bureau. (2024, July 22) . Agriculture sector has registered an averag e annual growth rate of 4.18 per cent over th e last five years: Economic Survey. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2034943
2. Reddy S.R., (2016). Principles of Agronom y. Kalyani Publishers. New Delhi.
3. Tiwary A. (2022). Precision Farming and Pr otected Cultivation. JNKVV, Jabalpur.

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Irrigation Scheduling Approaches: An Overview

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Irrigation Scheduling:

Water is a crucial component of crop cultivation. Even in humid areas, Precipitation is insufficient to meet the water requirements of plants. Thus, additional water is applied through irrigation. Irrigation management can be complicated with unpredictable precipitation patterns. Not watering at the right time and correct amount can result in plant water stress and reduce the quality and yields of crops. On the other hand, over-watering can increase the risk of nutrients leaching below the root zone, waste resources (water, energy, and nutrients), and environmental impacts. Therefore, it is important to apply irrigation at the right timing and correct amount. Determining the appropriate amount of irrigation and the optimal timing of irrigation are challenging due to unpredictable weather conditions and climate changes. Irrigation scheduling is a method of determining the appropriate amount of water to be applied to a crop at the correct time to achieve full crop production potential. Scheduling irrigation water has been based on the soil moisture measurement and/or weather data that are estimates of evapotranspiration. Good scheduling will apply water at the right time and in the right quantity in order to optimise production and minimise adverse environmental impacts. Bad scheduling will mean that either not enough water is applied or it is not applied at the right time, resulting in under-watering, or too much is applied or it is applied too soon resulting in over-watering.

Advantages of Irrigation Scheduling

Irrigation scheduling can offer several advantages as it can

1. Enable farmers to schedule watering to minimize crop water stress and maximize yields.
2. Reduce farmer's costs of water and labour through less irrigation, thereby making maximum use of soil moisture storage.
3. Lower fertilizer costs by holding surface runoff and deep percolation (leaching) to a minimum.
4. Increase net returns by increasing crop yields and crop quality.
5. Minimize water-logging problems by reducing the drainage requirements.

Approaches for Irrigation Scheduling:

Soil moisture regime approach	Climatological approach	Plant indicator approach
1.Feel and appearance method	1.PET measurement	1.Visual plant symptoms
2.DASM approach	2.IW/CPE approach	2. Soil-cum-sand mini-plot technique
3. Soil moisture tension method		3. Canopy temperature
		4. Leaf water potential
		5. Critical growth stages

A. Soil Moisture Regime Approach:

In this approach the available soil water held between field capacity and permanent wilting point in the effective crop root zone. Alternatively soil moisture tension, the force with which the water is held around the soil particles is also sometimes used as a guide for timing irrigations.

1. Feel and appearance of soil

This is one of the oldest and simple methods of determining the soil moisture content. It is done by visual observation and feel of the soil by hand.

2. Depletion of the available soil moisture (DASM)

In this method the permissible depletion level of available soil moisture in the effective crop root zone depth is commonly taken as an index.

In general, for many crops scheduling irrigation's at 20 25% DASM in the soil profile was found to be optimum at moisture sensitive stages.

Crop	Optimum soil moisture depletion level
Maize	25-50% DASM in Hyderabad, Andhra Pradesh
Sugarcane	25-65% DASM in Lucknow, Uttar Pradesh
Groundnut	25-40% DASM in Tirupathi, Andhra Pradesh
Cotton	65% DASM in Coimbatore, Tamilnadu
Sesame	50% DASM in Parbhani, Maharashtra
Leafy vegetables	20% DASM in Delhi
Tobacco	35% DASM in Rajahmundry, Andhra Pradesh
Wheat	50% DASM in Delhi & Jobner, Rajasthan

3. Soil moisture tension

Soil moisture tension a physical property of film water in soil, as monitored by tensiometers at specified depth in the crop root zone could also be used as an index for scheduling irrigations to field crops. Tensiometers are installed in pairs, one in the maximum rooting depth and the other below this zone.

B. Climatological Approach

In this method the water loss expressed in terms of either potential evapotranspiration (PET) or cumulative pan evaporation (CPE).

1. Potential evapotranspiration (PET)

It is defined as "the amount of water transpired in a unit time by short green crop of uniform height, completely covering the ground and never short of water". The concept of potential evapotranspiration was put forth by Thornthwaite (1948) and Penman (1948).

2. IW : CPE ratio

Parihar *et al*. (1976) advocated irrigation scheduling on the basis of ratio between the depth of irrigation water (IW) and cumulative pan evaporation (CPE). The irrigation depth (IW) for different crops are fixed based on the soil and climatic condition. The ratio of IW / CPE which gives relatively best yield is fixed for each crop by experiment with different rations. It gives best correlation compared to other formulae where climatic parameters and soil parameters (depth) are considered. Parihar *et al*., (2003) suggested a relatively more practical meteorological approach of IW/CPE, the ratio between a fixed amount of irrigation water (IW) and Cumulative Pan Evaporation, as a basis for irrigation scheduling to crops. IW/CPE approach merits special consideration on account of its simplicity of operation.

C. Plant Indicator Approach

1. Visual plant symptoms

In this method the visual signs of plants are used as an index for scheduling irritations. For instance, plant wilting, drooping, curling and rolling of leaves in maize is used as indicators for scheduling irrigation.

2. Soil-cum-sand mini-plot technique

The principle involved in this technique is to reduce artificially the available water holding capacity of soil profile (i.e., effective root zone depth) in the mini-plot by mixing sand with it. When this is done plants growing on the sand mixed plot show wilting symptoms earlier than in the rest of the field.

3. Canopy temperature

Canopy temperature measurement is a non-destructive and rapid method for determining water stress level in plants. This can be used as indicators for scheduling irrigation. Infrared thermometer is used to measure canopy temperature.

4. Leaf water potential

Leaf water potential is a simple indicator of leaf water status, the more negative the value, the more dehydrated the leaf. So leaf water potential can be used as an indicator for irrigation scheduling. LWP is measured using pressure chamber.

5. Critical growth stages

The crop plants in their life cycle pass through various phases of growth, some of which are critical for water supply. The most critical stage of crop growth is the one at which a high degree of water stress would cause maximum loss in yield.

References

1. Parihar, S. S., K. L. Sandhu and Sandhu, B. S. (1976). Comparison of irrigation schedule based on pan evaporation and growth stages in wheat. *Indian Journal of Agronomy*, 68: 650-653
2. Parihar, S. S. and Tiwari, R. B. (2003). Effect of nitrogen level on yield, nutrient uptake and water use of late sown wheat (*Triticum aestivum L.*), *Indian Journal of Agronomy*, 48(2):103-107

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Impact of Biotic Stress on Cropping System: A Meta-Analysis

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Introduction

Stress is 'a condition caused by factors that tend to alter an equilibrium', 'Stresses' that impact upon seeds can affect plant reproduction and productivity, and, hence, agriculture and biodiversity **(Strasser, 1998).** Biologically, stress is the factors that reduces normal function of individual which limits their genetic potential for growth, development and reproduction **(Levitt, 1980).** Biotic stress is stress that occurs as a result of damage done to plants by other living organisms. It includes bacteria, fungi, nematodes, viruses and insect- pests. According to **Wang *et al*. (2011),** the biotic stresses are responsible for approximately, 28.2%, 37.4%, 31.2%, 40.3%, 26.3%, and 28.8% yield losses in wheat, rice, maize, potatoes, soybeans, and cotton crops, respectively. It is estimated that insect pests cause 15–20% yield loss in principal food and cash crops in India. 600 insect and mite pests are present in temperate fruits alone in India **(Sharma and Singh, 2006).** Diseases both in field and storage accounts for 25-30 per cent losses in fruit crops. Furthermore, losses due to plant diseases not only hinder the crop productivity but also pose a huge risk to food and nutritional security, worldwide**.** Biotic stress includes attack by various pathogens such as fungi, bacteria, oomycetes, nematodes and herbivores.

Status of loses caused by Pests and Diseases

The FAO estimated that a total annual loss of 20 to 40% of global crop production is due to pests. Each year, plant diseases cost the global economy around $ 220 billion and invasive insects around $ 70 billion. While in India, crop yield loss is estimated as 26, 20, 6, and 8% by insects, plant pathogens, rodents, and others, respectively, with an annual loss of 225,000 crore (1 crore = 10 million) annually **(Kumar *et al*., 2021)**. Weeds usually require external efforts to be excluded from the cropland and eventually reduce the economy, deteriorate the environment, human health, and amenity. Weeds alone account for 37% of total annual crop yield loss in India.

Different Analyses of Biotic Stress's effect on Cropping System

1. **Foliar effects of pest damage caused by: A. reduction of leaf area indices (LAI), and B. reduced radiation use efficiencies (RUE)**

   From the insights of **Boote *et al.* (1983)** and summarization by **Madden and Nutter**, 11 foliar plant pathogens have been categorized into two groups: (1) those that reduce the amount of foliage or RI by a plant, and (2) those that reduce RUE of the foliage **(Figure 1)**. Those pathogens that reduce the amount of foliage or RI do so by consuming foliage, accelerating leaf senescence, reducing plant stands, and/or stealing light. Then there are pathogens that interfere with the RUE of the photosynthetic process in the leaf by consuming assimilates, reducing the photosynthesis rate, and reducing plant turgor. Both categories of pathogens ultimately reduce the net photosynthetic ability of an infected plant compared to a healthy non infected plant.

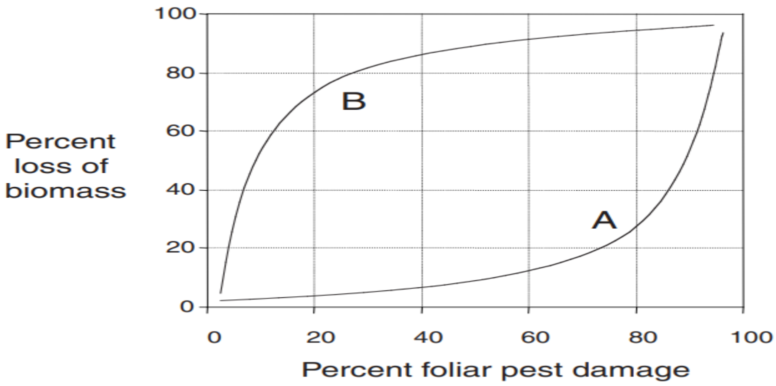

Figure 1: Foliar effects of pest damage caused by: A. reduction of leaf area indices (LAI), and B. reduced radiation use efficiencies (RUE)

2. The relationship between the total radiation intercepted by a crop canopy and the biomass production

Until the late 1980s, the majority of studies investigating the relationship between diseases and crop yield attempted to correlate only disease severity or incidence at a single point or multiple points in time with yield or AUDPC and yield. Most of the correlations only had limited accuracy and did not predict yields at different locations or years. **Waggoner and Berger, (1987)** clarified the relationship between disease and yield. They explained that disease symptoms reduce the healthy LAI of a plant. Consequently, the plant assimilates less biomass compared to a healthy plant. They used two equations to analyse data previously published in refereed journals. The first equation integrates the effects of the disease on the healthy (disease free) LAI throughout the growing season. The second equation integrates the effects of the disease on the LAI and radiation absorption throughout the growing season, similar to that used by Khurana and McLaren.

Values from each equation were correlated with yield. When HAD was plotted against yield, the two spring crops and one autumn crop each had different regression lines.28, 29 The slopes of the regressions for the two spring crops were similar but much steeper than the autumn crop. The HAD equation does not consider any differences in incident radiation and RI. Solar radiation is significantly less in autumn compared to spring and early summer months. When the same data were plotted using the HAA equation, a single regression line fit both spring crops and autumn crops (**Figure 2**). This clearly supports the use of the RI equation to calculate biomass production of crops and yields.

Agronomic Innovation for Insect-pests, Diseases, Weeds and Nematodes Management

- Soil solarisation
- Summer/deep ploughing
- Growing resistant varieties/ competitive crop cultivars
- Crop rotation
- Time, method, depth and density of sowing/ planting
- Fertilizer and nutrition management
- Irrigation method
- Habitat management
- Biological control
- Bio-fumigation

Innovations in Biotic Stress Management

- Precision pest–management technology
- Biological pest suppression
- Conservation tillage
- Nano-pesticides
- Remote sensing
- Artificial intelligence
- Bio-pesticides

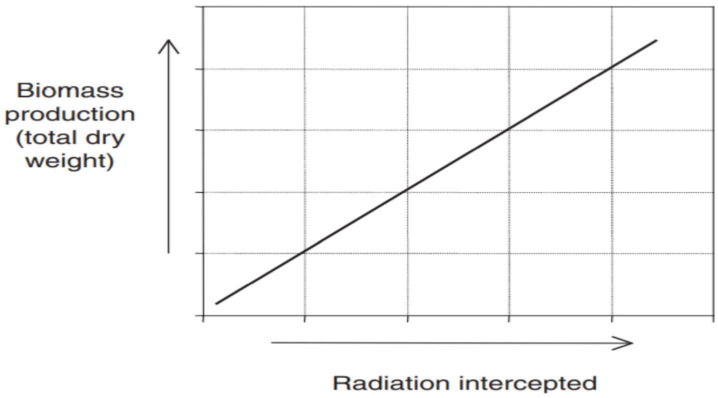

Figure 2: The relationship between the total radiation intercepted by a crop canopy and the biomass production.

Mitigation Strategies of Biotic Stress

- The most prevalent tools to control plant, pests and enhance soil fertilely are the use of intensive agrochemicals irrespective of their high cost and deleterious impacts on health and environments.
- Variety selection and the use of fungicides are two management strategies that producers should consider to improve economic return.
- Genetic improvement of plants through biotechnology to tolerate, or be resistant to, biotic stresses will be a key component of future global food security as these stresses can result in substantial yield losses globally each year.
- Genetic improvement of crops via genetic engineering and other biotechnology approaches will be needed to complement, or replace, traditional breeding efforts as they make available a broader range of genes such as AMPs, etc. and can be used in a more precise manner than traditional breeding.
- Innovations in biotic stress management should include nano-technology in pest management, fumigants, post-harvest and vertebrate pest management, identification of broad-spectrum resistance, utilizing wild species genepool, deployment of remote sensing technology for pest management.
- Eco-friendly pest management technologies are best alternative to chemical control which are environmentally complementary/ focused with special attention to food security and sustainability
- Precision on pest survey/ surveillance will be more if based upon artificial intelligence by establishing an automated detection system applying remote sensing, image processing, soft computing etc.

Conclusion

Food crops in India suffer from many newly emerging and invading biotic stresses, i.e. insect pests/ diseases/weeds. For sustainable food production, it will be worthwhile to switch into novel mitigation measures rather than protecting the crops by traditional methods of pest management which are now outdated and incompetent. Emphasis must be laid on the identification of novel mitigation measures based upon molecular markers, transgenes, gene-editing technologies, nanotechnology, etc. In the future, the establishment of national referral laboratories for quick identification/ diagnosis and containment in order to prevent the widespread of pest, well–defined and coordinated mechanism should be developed for safeguarding our country, Artificial Intelligence for monitoring, etc. Much success has been achieved for enhancing yield traits using such technologies but research is limited in breeding for biotic stress–resistant varieties against key pests. It is the duty of researchers to develop

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stress tolerant cultivars in order to secure food security and to ensure safety to the farmers.

References

1. Boote, K. J., Jones, J. W., Mishoe, J. W., and Berger, R. D. (1983). Coupling pests to crop growth simulators to predict yield reductions, Phytopathology, 73, 1581,

2. Kumar, J., Murali-Baskaran, R. K. (2021). Biotic stresses of agricultural crops in India: re-visiting national status and mitigation strategies. ICAR-National Institute of Biotic Stress Management, Raipur 493 225, India.

3. Wang, Y., Kim, S.G., Agarwal, G.K. (2011). Biotic Stress-Responsive Rice Proteome: An Overview. J. Plant Biol. 54:219–226

4. Waggoner, P. E., and Berger, R. D., (1987). Defoliation, disease, and growth, Phytopathology, 77, 393.

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Mapping Plant Health from Space: The Fusion of Remote Sensing, Soil Science, and Pathology

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Introduction

In the era of precision agriculture, the intersection of plant pathology, soil science, and geospatial technology is transforming how we detect, monitor, and manage crop diseases. Traditionally, diagnosing plant diseases relied on visual inspection and field sampling methods that are often labor-intensive, subjective, and too slow to contain fast-spreading outbreaks. But today, satellites, drones, and sensors are changing the narrative by offering real-time, large-scale insights into crop health and environmental conditions. Remote sensing, through optical, thermal, or hyperspectral imaging, allows for the early detection of plant stress signals—long before symptoms become visible to the naked eye. Changes in leaf reflectance, canopy temperature, or chlorophyll fluorescence can indicate biotic stresses caused by pathogens or insects, or abiotic stresses like nutrient deficiency or salinity (Mahlein, 2016; Calderón et al., 2013). These signals, when interpreted correctly, act as an early warning system for disease outbreaks.

When combined with Geographic Information Systems (GIS), this data becomes even more powerful. GIS enables spatial visualization, mapping, and analysis of disease hotspots, historical outbreak trends, and the relationships between soil properties, topography, climate, and disease prevalence (Nelson et al., 1999). This integration allows researchers and farmers to precisely locate infected areas, assess disease spread patterns, and deploy control measures exactly where they are needed, minimizing input costs and maximizing crop protection. Moreover, the role of soil health in disease occurrence is often underestimated. Soil pH, moisture, organic matter, microbial communities, and nutrient status directly influence the soilborne pathogen activity and plant immunity (Schlatter et al., 2017). By fusing soil science data with remote sensing and GIS, scientists can develop predictive models to assess disease risk zones, especially for root and wilt pathogens such as *Fusarium*, *Phytophthora*, and *Rhizoctonia*.

This synergy of disciplines is ushering in a new age of digital plant pathology—one that is not only reactive but proactive, predictive, and precise. In countries like India, Brazil, and the U.S., such technologies are already being tested and adopted in crops like rice, wheat, sugarcane, and maize for mapping diseases such as rice blast, wheat rust, and late blight of potato (Lelong et al., 2008; Zhang et al., 2019). As we look to feed a growing global population under increasing climate pressures, the fusion of remote sensing, soil science, and plant pathology offers a powerful toolkit for building resilient and informed agricultural systems. This article explores how this technological convergence is helping us map, monitor, and mitigate plant disease threats from space to soil.

1. Remote Sensing: Seeing Plant Stress Before It Strikes

Remote sensing technologies ranging from satellite imagery (like Sentinel-2 and Landsat-8) to UAVs (drones) provide a bird's-eye view of crop fields. These tools detect subtle spectral signatures associated with plant physiological changes due to disease stress. When a pathogen infects a plant, it alters water content, pigment concentration (e.g., chlorophyll), and leaf structure. This results in changes in Normalized Difference Vegetation Index (NDVI), Photochemical Reflectance Index (PRI), and thermal patterns (Mahlein et al., 2013). For example, hyperspectral sensors can detect infections like early blight in tomato or leaf rust in wheat before visual symptoms appear. These technologies allow for early warning systems, enabling farmers to intervene before disease spreads.

2. GIS: Mapping Disease Dynamics in Space and Time

GIS enables the spatial and temporal mapping of disease progression. By integrating field data, remote sensing inputs, and environmental variables (elevation, humidity, soil pH, etc.), GIS models can predict hotspots and simulate disease spread. An effective example is the "FAMEWS" (Fall Armyworm Monitoring and Early Warning System) developed by FAO, which uses mobile inputs, satellite data, and GIS to track *Spodoptera frugiperda* spread across Africa and Asia. In India, GIS models are also being used to monitor rice sheath blight and blast disease distribution across states, helping in strategic fungicide deployment and breeding site selection.

3. Soil-Pathogen Interactions: The Underground Connection

Soil is not just a medium for plant growth—it is the first line of defense against many pathogens. Properties such as organic matter, pH, microbial biodiversity, and moisture retention influence the survival and spread of soilborne pathogens like *Fusarium*, *Phytophthora*, and *Pythium*. Digital soil maps, derived from spectral soil sensors and legacy data, help identify disease-conducive soils. For instance, acidic, poorly-drained soils are often associated with *Phytophthora* root rot in crops like pepper and citrus (Schlatter et al., 2017). Integrating soil data into GIS and remote sensing platforms improves the accuracy of disease risk models and allows for precision soil amendments (e.g., liming or organic additions).

Case Studies

1. Hyperspectral Detection of Rice Blast in Tamil Nadu, India

Researchers from Tamil Nadu Agricultural University (TNAU) used UAV-mounted hyperspectral cameras to detect rice blast disease in MTU-1001. By identifying changes in chlorophyll absorption bands and leaf water indices, they could pinpoint infection as early as 3 days post-inoculation, well before symptoms were visible. This helped reduce fungicide usage by 35% in field trials through timely interventions (TNAU Precision Farming Lab, 2022).

2. Mapping Late Blight of Potato in Peru

In the Peruvian Andes, scientists used satellite data (MODIS NDVI) and GIS tools to track Phytophthora infestans outbreaks. The study revealed that topography and nighttime humidity strongly influenced disease intensity. The results guided localized early-warning systems and influenced resistant cultivar deployment (Forbes et al., 2014).

3. Soil Mapping for Wilt Management in Chickpea, India

ICRISAT developed soil health maps integrating pH, EC, and microbial activity to identify Fusarium wilt-prone zones in chickpea-growing regions. Using GIS overlays, they provided site-specific bio-control and organic input recommendations, reducing disease incidence by over 40% in target zones (Ghosh et al., 2016).

Conclusion

As global agriculture navigates the twin pressures of increasing food demand and mounting environmental challenges, the fusion of remote sensing, GIS, soil science, and plant pathology emerges as a transformative strategy. These technologies collectively offer a shift from traditional, reactive plant health monitoring to a proactive, data-driven approach. By enabling early detection of disease outbreaks, spatial mapping of risk zones, and integration of soil health indicators, this interdisciplinary model promotes targeted interventions, resource optimization, and ecological sustainability. The importance of this synergy cannot be overstated. Remote sensing provides the "eyes," GIS offers the "intelligence," soil science supplies the "context," and plant pathology delivers the "cause and consequence." When these fields converge, they form a powerful ecosystem for disease surveillance and management capable of delivering real-time insights and enabling precision agriculture at scale.

Future Perspectives

Looking ahead, emerging technologies will further elevate this convergence into a next-generation disease management platform:

1. AI and Machine Learning in Plant Health Prediction

Machine learning models, trained on large-scale satellite imagery, soil maps, and disease databases, will predict outbreak risks with unprecedented accuracy. AI-based classification systems can distinguish between multiple stress factors—be it pathogen attack, nutrient deficiency, or drought—based on spectral and thermal signatures (Mahlein, 2016).

2. Real-time Monitoring via IoT Networks

Internet of Things (IoT) devices such as leaf wetness sensors, soil moisture probes, and canopy temperature sensors are being deployed in smart fields. These devices stream continuous, real-time data to cloud-based platforms, where algorithms analyze them for early disease warnings, enabling automated decision support and rapid farmer response.

3. Soil Metagenomics for Microbial Mapping

Advanced molecular tools, including soil metagenomics and microbiome profiling, will help monitor both pathogenic and beneficial microbes in the rhizosphere. This will not only support microbe-based disease forecasting but also allow for the tailored application of bioinoculants, fostering healthier, disease-resilient soil ecosystems.

4. Democratization through Open Data Platforms

Governments and research institutions are investing in open-access platforms such as BHUVAN (India), Google Earth Engine, and Copernicus (EU), making satellite-derived data accessible to farmers, extension agents, and agritech companies. When integrated with mobile apps, these tools will offer location-specific crop health alerts, diagnostic insights, and input recommendations.

5. Policy and Farmer-Centric Innovations

To truly harness the potential of this digital fusion, policy support, interdisciplinary collaboration, and grassroots training are vital. Initiatives should focus on building digital literacy among farmers, subsidizing remote sensing services, and fostering collaborations between agronomists, soil scientists, data analysts, and pathologists.

References:

1. Calderón, R., Navas-Cortés, J. A., & Zarco-Tejada, P. J. (2013). Early detection and quantification of Verticillium wilt in olive using hyperspectral and thermal imagery over large areas. *Remote Sensing*, 5(11), 4729–4740.
2. FAO (2019). FAMEWS: Fall Armyworm Monitoring and Early Warning System. https://www.fao.org/fall-armyworm/monitoring-tools/famews
3. Forbes, G. A., Juarez, H., & Hijmans, R. J. (2014). Predicting and mapping the potential impact of late blight on potato production in the Andes. *Phytopathology*, 104(11), 1181–1191.
4. Ghosh, R., Sharma, M., Telangre, R., & Pande, S. (2016). Integrated soil management for suppression of chickpea wilt. *Plant Disease Research*, 31(1), 23–30.
5. Lelong, C. C. D., Burger, P., Jubelin, G., Roux, B., Labbe, S., & Baret, F. (2008). Assessment of unmanned aerial vehicles imagery for quantitative monitoring of

6. wheat crop in small plots. *Sensors*, 8(5), 3557–3585.
7. Mahlein, A. K. (2016). Plant disease detection by imaging sensors – Parallels and specific demands for precision agriculture and plant phenotyping. *Plant Disease*, 100(2), 241–251.
8. Mahlein, A. K., Steiner, U., Hillnhütter, C., Dehne, H. W., & Oerke, E. C. (2013). Hyperspectral imaging for small-scale analysis of symptoms caused by different sugar beet diseases. *Plant Methods*, 9(1), 20.
9. Nelson, A., You, L., & Wood, S. (1999). A GIS-based approach to assessing the risk of plant disease outbreaks. *Plant Pathology Journal*, 15(3), 143–154.
10. Schlatter, D., Kinkel, L., Thomashow, L., Weller, D., & Paulitz, T. (2017). Disease suppressive soils: New insights from the soil microbiome. *Phytopathology*, 107(11), 1284–1297.
11. Schlatter, D., Kinkel, L., Thomashow, L., Weller, D., & Paulitz, T. (2017). Disease suppressive soils: New insights from the soil microbiome. *Phytopathology*, 107(11), 1284–1297.
12. TNAU Precision Farming Lab Report (2022). Remote sensing applications for early detection of blast in rice. Tamil Nadu Agricultural University, Coimbatore.
13. Zhang, M., Qin, Z., Liu, X., & Ustin, S. L. (2019). Detection of stress in tomatoes induced by late blight disease in California, USA, using hyperspectral remote sensing. *International Journal of Applied Earth Observation and Geoinformation*, 74, 41–49.

BIOFORTIFICATION OF VEGETABLE CROPS

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Vegetables constitutes an integral portion of our daily staple diet. According to recent statistical data related to nutrition, it has been observed that a significant portion of population is suffering from nutrient deficiency called “hidden hunger”. It is the need of the hour to increase the concentrations of the essential vitamins and mineral composition in the staple vegetables. To address this global problem, a novel scientific approach has evolved which is termed as “bio-fortification”. This term focuses on raising the concentration of essential vitamins and minerals such as Vitamin A, β-carotene content, iron, zinc, folate and Vitamin C content in vegetables. This technique of improving the density of nutrients is achieved by adopting the conventional breeding methods or genetic/transgenic process or by agronomic process by altering the fertilizer dose or enabling proper soil management practices techniques. Several vegetable varieties like beta-carotene rich orange fleshed sweet potatoes, folate, iron and zinc enriched spinach, Vitamin C and lycopene rich tomatoes and high-folate content in cauliflower.

Keywords: Biofortification, nutrition, vegetables, micro-nutrients, health

Introduction

Most countries face problems like malnutrition, hunger, food loss,food waste, and lack of vitamins, minerals, etc. From 2019 to 2021 global hunger has risen sharply with the same level until 2023. In 2023 global hunger has affected 9% of the total world population. India ranks 105th out of 127 countries, ranked by Global Hunger Index, in 2023. According to the United Nations, there are nearly 195 million undernourished people in India making up a quarter of the world's undernourished population. Additionally, 43% of children in India are suffering from malnutrition. Biofortification is derived from two words i.e. “Bios” comes from the Greek word, which refers to life, and “forticare” comes from the Latin word which refers to make firm. Collectively, it is the process in which the nutritional value of a crop is increased. Increasing the nutrient status involves various methods, such as agronomic biofortification, conventional plant breeding, and genetic engineering. The number of minerals like Zinc (Zn), Magnesium (Mg), Calcium (Ca), Iron (Fe), Selenium (Se), Iodine, and vitamins like vitamin A and Folate (also known as vitamin B9 or folic acid)can be maintained in this process. It also helps in reducing health problems in the human body due to the deficiency of vitamins and minerals. For example, it helps to reduce the problem of malnutrition due to micronutrients. Biofortification takes places more emphasis on improving the nutrient content in different crops which helps to provide improved health to humans.

Biofortification of Vegetable Crops

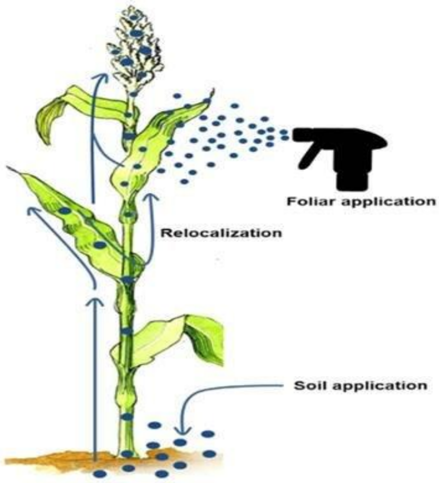
It refers to increasing the essential nutrients, and vitamins in vegetable crops which helps improve the food quality and provide public health benefits. The biofortification process has been done successfully in most vegetable crops like cassava, banana, beans, orange sweet potato (OSP), potato, pumpkin, cowpea, etc. It provides a sustainable and long-term means of delivering more micronutrients like Iron (Fe), Zinc (Zn), Selenium (Se), etc & vitamins like Vitamin-A, Vitamin-E, and Vitamin-K. It helps to reduce the anti-nutrients like Phytic acid, Glutein, Lectin, Saponin, and Glucosinolates to increase the bioavailability of micronutrients.

Methods of Biofortification

Biofortification can be obtained by three approaches which includes the i. Agronomic biofortification ii. Conventional plant breeding iii. Genetic engineering and gene editing.

i. Agronomic biofortification:

Fertilizer is an inorganic chemical that is used to add nutrition to the crop. There are several techniques used in this biofortification which are nutri-priming, foliar application, soilless cultivation, soil application, microbe-mediated biofortification, organic fertilizer, bio-fertilizer, etc. mostly in the edible part of the crop micronutrient has been maintained by using micronutrient rich fertilizers. The most important micronutrients that can be used for the agronomical approaches are zinc which can be added by foliar application of $ZnSO_4$, $ZnCl_2$, Manganese added by foliar application of $MnSO_4$, Iodine can be added to the soil by iodide or iodate application. It is the easiest and quickest method used in those areas where genetic engineering is not applicable. For improving nutrients like Zn, Se, Mn, and Fe in the crop, mycorrhizal association with higher roots of plants plays a key player. This method is completed by three processes i.e. a. soil to crop- in this plant uptake nutrients directly from the available soil nutrient,b.crop to food this process nutrient allocation takes place inside the crop plant and translocates into harvested food, c. food to human this process the available nutrients present in the crop are absorbed by the human body.



ii. Conventional plant breeding:

It is the science that is used for improving the genetic properties of cultivated crops. Recently there has beena large progress in conventional plant breeding for the fortification of several micronutrients (Zn, Fe, Se) and vitamins. It involves ten steps -1. The target populations have been identified 2. The target levelsof nutrients have been set 3. Screening of the germplasm and gene hasbeen done 4. Breeding for biofortified crops has been done 5. The performance of new crop varieties has been tested 6. The nutrient retention in crops/food has been measured 7. The impact and absorption of nutrients has been evaluated 8. For disseminating seeds strategies have been developed 9. The promotion has been done for the marketing & consumption of biofortified food 10. The nutritional status of the target population has been improved. In staple foods like rice, potato, cassava, etc. the micronutrient density should be increased, this requires genetic variation in concentrations of Fe, Zn, carotenoids, vitamin A, etc. It is successfully carried for minerals and vitamins, one-off cost, easier distribution, and long-term strategies. An example of this approach is to increase the iron and zinc levels and up to a 6.6-fold variation have been reported in beans and peas (Gregorio

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et al., 2000) and concentrations in strawberries differed less than two-fold 14. The particular trait for the biofortification of vegetables should be stable between generations.

iii. Genetic Engineering-

Most crops lack desired traits or characteristics to solve this problem genetic engineering is mainly adopted. It helps to provide new variation to the crop. It is mostly suitable for crops that are not used in conventional breeding because of lack of sexuality. Comparatively requires less time than conventional breeding. It includes new breeding technologies like biofortification, CRISPR-mediated biofortification, gene over expression, foreign gene transfer, etc. This method mostly focuses on gene flow i.e. process of transfer of genetic materials from one population to another. From 1996 to 2015 biotech crop hectares has been increased by more than 100-fold from 1.7 million hectares to 179.7 million hectares respectively. In 1996, the Flavr-Savr tomato was introduced and it hit the record of 175.2 million hectares in 2013.

Early the growth rate of biotech crops was 3 percent (James et al., 2013). This massive growth rate starting from 1.7 million hectares in 1996 to 175.2 million hectares in 2013 makes biotech crops the most rapidly adopted crop technology in the near past.

A transgenic crop is also known as a genetically modified crop which helps to provide better nutritional quality, resistance against insects and pests, and also increases the level of micronutrient content. Vegetable breeders use different genetic engineering technologies to develop new varieties with high yields and more nutrition. Example – Golden rice was introduced in the year 2000. It is rich in vitamin A and provides 50% of the estimated average requirement.

Function of Micronutrients in the Human Body-Micronutrients are vitamins and minerals needed by the body in very small amounts. It helps the body to produce different enzymes and hormones which help in proper growth and development. Its deficiency can cause several diseases like anaemia, reduced hemoglobin level, Weakness, goitre, Pellagra, etc.

- **Zinc-**

Zinc is found in cells of the whole body. It is needed for the body's defensive (immune) system to properly work. It plays a role in cell division and cell growth. Zn plays an important role in maintaining cardiovascular health by maintaining blood pressure. It also helps in wound healing and hair growth.

- **Iron-**

Iron is a critical component of the body. Its primary role is to store and transport iron (as myoglobin and hemoglobin) throughout the body. It helps to deliver oxygen to our bodies and also maintain energy levels. It involves the production of enzymes, new cells, amino acids, etc.

- **Copper-**

Cu is a mineral that is found throughout the body. It helps in making connective tissues and maintaining energy levels. It helps in keeping the healthy function of our brain and nervous system, helps in the transportation of Fe throughout the body, and produces melanin which is useful for the skin.

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Biofortified Vegetable Varieties

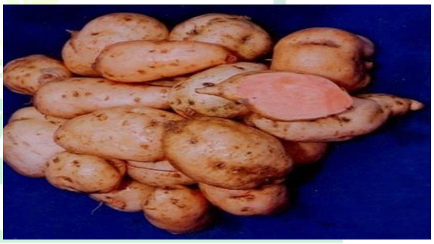
Biofortified Brinjal Variety
Pusa Safed Baigana -1

Biofortified Sweet Potato Variety
Bhu Sona

3. Biofortified Carrot Variety Pusa Asita

4. Biofortified Sweet Potato Variety
Bhu Krishna

5. Biofortified Carrot Variety Pusa
Rudhira



6. Biofortified Potato Variety
Sree Kanaka

7. Biofortified Cauliflower Variety
Pusa Betakesari

8. Biofortified Potato Variety Kufri
Neelkanth

9. Biofortified Turnip Variety Pusa
Gulabi

10. Biofortified Carrot Variety
Pusa Meghali

- **Selenium-**

Selenium is one of the most important micronutrients; it is a constituent part of selenoproteins. Selenoprotein is involved in improving human metabolism. It helps to prevent cancer and protects cells against damage from free radicals. It supports the immune system, thyroid function, reproduction system, hormone metabolism, and DNA synthesis protecting the body from oxidative damage and infection.

Importance of Biofortification-

In the early 1990s, biofortification stood out as a game changer for improving overall health improvement, the global micronutrient challenge of people has been examined by Howarth "Howdy" Bouis, who was a young economist at the CGIAR's International Food Policy Research Institute (IFPRI). Biofortified crops have more resistance to biotic stresses like diseases and pests & abiotic stress like droughts, etc., and also help in providing more yields.

- The process of biofortification improves micronutrients and vitamins and reduces problems like malnutrition, hunger, etc.
- This is a sustainable agriculture method in which natural production does not affect biofortification, and the solution has been given to the hands of farmers.
- Farmers are more preferred to combine the micronutrient trait with other traits such as agronomic and consumption traits.
- Measure and track the production, distribution, and consumption of biofortified crops.
- Increase budgetary allocation to biofortification interventions i.e. implementation and research & development.

Conclusion

Biofortification is the best cost-effective method for improving the nutrient content of soil. It helps increase the essential micronutrients Zn, Se, Cu, Fe, etc. It can reduce health problems like hunger, malnutrition, etc. It involves different plant breeding methods. It is the easiest method which can be adopted by farmers. This method is essential for market adaptation. Reduction in anti-nutrients such as phytic acid or tannins is the recent advancement of genetics which involves enhancing the quantity of micronutrients. For the exploitation of biofortified crops, there is a need for genome editing tools like Prime Editing, Base Editing, ZFNs, TALENs, CRISPR-Cas9,Cas12 & Cas13, etc. which also help in editing the plant genes' undesirable traits.

References-

1. Black RRE, Allen LHL, Bhutta ZZA et al (2008) Maternal and child undernutrition: global and regional exposures and health consequences. Lancet 371:243–260
2. Biofortification of Vegetables Anil Kumar Jena1 , Geetashree Bora2 ,Pranamika Sharma1 , Rimi Deuri and Surya Prakash Singh
3. Biofortification of Vegetable Crops - A New Tool to Alleviate Micronutrient Malnutrition Barsha Tripathy1 , Pradyumna Tripathy2 , Priyanka Sahu2 , Sandeep Rout3 and M. Sai Sindhu1
4. Chakraborty, S., N. Chakraborty and A. Datta. 2000. Increased nutritive value of transgenic potato by expressing a nonallergenic seed albumin gene from Amaranthushypochondriacus. Proc. Natl. Acad. Sci. (USA), 97: 3724-3729.
5. Current Acquaintance on Agronomic Biofortification to Modulate the Yield and Functional Value of Vegetable Crops: A Review
6. Draghici G.A., Lupu Maria Alexandra, BorozanAurica – Breica, Nica D., Alda S., Alda Liana, Gogoasa I., Gergen I., Bordean Despina-Maria.2013. Red cabbage is, millennium's functional food. Journal of Horticulture, Forestry And Biotechnology, 17(4): 52- 55.
7. Frontiers in horticultural sustainability (Volume-1): Chapter 7-Biofortification in Vegetable Crops (SandhyaLamichaney, Dr Rajesh Kumar, Prakash and RadhakantaThanjam).
8. Gómez MI, Barrett CB, Raney T et al (2013) post-green revolution food systems and the

triple burden of malnutrition. Food Policy 42:129–138.

9. Gupta, S. 2014. Commercialization of transgenic horticultural crop: challenges and future prospects. Annals of Horticulture, 7(2): 129-134.

10.James, C. 2013. Global status of commercialized biotech/GM crops: 2013. The international service for the acquisition of agri-biotech applications (ISAAA)

11.Modern concept in agriculture: Chapter - 15 Biofortification in Vegetable Crops MohdWamiq, KhursheedAlam, Muzeev Ahmad and SurajLuthra

12.Singh et al., 2021. Biofortification of Vegetable Crops. Biotica Research Today 3(10): 819-824.

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Water Apple: The Juicy Gem of the Tribal Andhra Pradesh

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In the lush green hills of Alluri Sitarama Raju (ASR) district of Andhra Pradesh, thrives a fruit that is juicy, healthy, delicious, succulent and yet largely untapped — is the Water Apple (*Syzygium aqueum*), also known as ***watery rose apple*** or simply, ***rose apple***. It belongs to the family Myrtaceae and is native to South East Asian countries and to certain tropical regions of India where there is cool climate and red loamy soil; the conditions naturally found in the Tribal Andhra Pradesh ie; Araku - Chintapalle belt. It is commonly referred to as "*Chambakka*" or "*Pani Seb*" in Hindi, "*Jambu*" or "*Panneer Naval*" in Tamil, "*Jambakka*" in Malayalam and "*Gulaabi jamichettu*" or "*Gulaabi jamikaayalu*" in Telugu. Due to their crispy texture, refreshing taste, and thirst-quenching properties it is a perfect summer snack. Though its delicate in texture and underutilised it has emerging prospects as a hidden gem in the tribal belts of Andhra Pradesh.

The plant are often grown in backyard farms and community groves. They grow up to a height of 3 to 10 meters and blossoms in the summer months of May through August, with pale green, cream and white flowers in full bloom. From August through November, upon developing, the fruits are creamy-green in color (green water apple) and turn a bright pinkish-red once completely ripened (water apple or rose apple). The ripe water apple fruits are bell-shaped, and have crimson-colored skin on the outside encompassing a white, juicy flesh within. They ooze a mildly pleasant aroma and usually have one or two grey seeds in the interior. These luscious water apple fruits have an intrinsically crunchy texture and are quite sweet in taste when ripe. However, the unripe green water apple possesses a characteristically astringent flavour and hence is ideal for use in the preparation of pickles, curries, and chutneys.

Nutritional Benefits of Water Apple

Water apple confers several benefits for human health and is prized for its therapeutic applications for treating various ailments, including heart conditions and liver disorders. The unique medicinal properties of this fleshy fruit are well-documented in traditional Indian practices of medicine - Ayurveda, Siddha and Unani.

Nutrient Content of Water Apple in (g) and (%) per 100 g		
Liquid Content		
Water	93.0 g	90%
Macronutrients		
Proteins (Total Protein)	0.6 g	1%
Carbohydrates (Total Carbohydrates)	5.7 g	2%
Dietary Fiber	1.5 g	0.5%
Starch	0.0 g	0%
Sugars	0.0 g	0%
Fats (Total Fat)	0.3 g	0%
Cholesterol	0.0 mg	
Micronutrients		
Vitamins		
Vitamin C	156 mg	25%
Vitamin A	22 mg	5%
Vitamin B1 (Thiamine)	10 mg	2%
Vitamin B3 (Niacin)	5 mg	1%
Minerals		
Calcium	29.0 mg	3%
Iron	0.1 mg	0.1 %
Magnesium	5.0 mg	1%
Phosphorus	8.0 mg	1%
Potassium	123 mg	20%
Sodium	0.0 mg	0%
Sulphur	13 mg	1.5%

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The water apple fruit is ideal for weight loss due to its low-calorie content and negligible amounts of saturated fats. In addition, it also provides dietary fibers, to aid in digestion and has no cholesterol, for better heart function. Water apples are rich in Vitamin C for boosting immunity and Vitamin A for proper vision. They are also abundant in the B vitamins that can aid in regulating metabolism. In addition, they possess vast amounts of crucial trace minerals like iron and calcium and antioxidants, which monitor enzyme function and prevent free radical damage in the body cells. The leaves also contain powerful plant compounds called flavonoids, which offer anti-inflammatory properties for those suffering from chronic conditions.

Due to its amazing nutritional profile, it caters the following functional benefits.

- **Anti-oxidative properties:** It is rich in Vitamin C and other phenolic compounds called flavonoids. These prevent the damage of cells due to free radicals, pollutants and toxic chemicals which lead to health ailments such as heart disease, cancer and arthritis. The antioxidant property of water apples effectively combats toxins in the body. Thus, it eliminates the oxidative damage effectively boosts the immune system of the body.
- **Anti-inflammatory:** Due to the negligible amounts of sodium and cholesterol in the water apple, its good for cardiac health as it lowers the health ailments such as inflammation, oxidative damage, atherosclerosis, blood pressure and endothelial health. The development of plaque in the body results in the stroke or heart attack which could be reduced with the Vitamin C. Also due to Niacin, it enhances good HDL Cholesterol levels and reduces the amounts of harmful triglycerides and bad LDL cholesterol in blood.
- **Improves Metabolism:** Consuming water apples in routine diet helps to speed up the assimilation of carbohydrates, fats and proteins in food, by acting as a catalyst to enzymes in biochemical processes. This in turn promotes proper appetite and metabolism and helps maintain optimal body weight.
- **Prevents Constipation:** Dietary fiber in water apple supports the digestive system in the material movement and adds bulk to the stool which is helpful for those having the irregular bowel function or constipation. It supports in healthy weight and reduces the chances of heart disease and diabetes.
- **Heals Muscle Cramps:** Water apple possess adequate amounts of potassium and water. It enhances the strength of muscles and reduces the muscle cramps often caused due to the low levels of potassium, sodium and dehydration.
- **Hepatoprotective:** It cures liver damage caused due to the excessive consumption of alcohol, anaemia, malnutrition, infection, and hepatotoxic drugs.
- **Anti-hyperglycemic properties:** They are good in lowering the blood sugar levels in patients with diabetes as they have a low glycemic index. Jambosine is a bioactive crystalline alkaloid present in water apples that suspends the conversion of starch into sugar thereby regulating the sugar level, especially in diabetic patients.

Water Apple Applications In Ayurveda:

- **Treats Epilepsy And Seizures:** The bioactive constituents in water apples known as terpenoids help in improving nerve function. Hence, it is effective as remedy for those suffering from neuronal complications like seizures.
- **Heals Oral Thrush:** The bark extract is crushed and applied on microbial infections in the mouth known as oral thrush, to heal the sores and swelling.
- **Remedies Kidney Stones:** The leaf extracts of water apple possess strong anti-inflammatory properties, which help to get rid of kidney stones within the system and

- ensure smooth elimination of toxins and bladder function.

Tribal Livelihoods

For many tribal communities of ASR district, water apples are not just a seasonal treat but a source of livelihood. Women and small farmers collect the fruits during the short season (May–July) and sell them in local markets or to forest cooperatives. However, the commercial potential remains under-explored due to lack of awareness, processing infrastructure, gaps in post-harvest processing and market access.

Processing Possibilities

Water apples have a short shelf life, but their high water content and mild sweetness make them ideal for processing into Juice and squash, Jelly and jam, Pickles with spices, Dried slices or fruit leather, Fermented beverages (like wine or vinegar). Simple value addition at village level can increase income 3–5 times more than selling raw fruits.

Business & Market Opportunities

With growing interest in local, seasonal, and functional foods, water apple-based products can find a niche in Urban organic stores, Tribal product exhibitions, E-commerce platforms and Eco-tourism stalls in Araku. Support from tribal welfare departments, NABARD, KVKs, and NGOs can aid in capacity building, FPO formation, and market linkage.

Water apple processing is a sustainable, low-investment business ideal for tribal youth, SHGs, and farmers in Alluri Sita Rama Raju district. With simple tools and training, it can transform a perishable fruit into high-value products for local and wider markets. The humble fruit holds the promise of becoming Andhra Pradesh's next super fruit, especially when nurtured in the capable hands of its tribal communities. With the right policy support and local innovation, this juicy gem can truly shine not just as a fruit, but as a symbol of sustainable tribal entrepreneurship.

Processing Possibilities

S.No.	Product	Processing methods	Shelf life	Use
1.	Fresh Juice	Wash and chop fruits. Remove the seeds and blend the chopped pieces with lemon juice and sugar or mint. Filter and pasteurize the juice and store in bottle and refrigerate	5–7 days (Refrigerated) and 30–60 days with preservatives	Local juice sale or tribal cooperative bottling
2.	Dehydrated Water Apple (Dried Slices	Slice into thin and Soak in lemon or salt solution. Dry under solar dryer or hot air dryer and Pack in moisture-proof pouches	3–6 months	As Dried fruit snacks or in herbal teas. Ideal for Local SHGs with solar dryers
3.	Jam/Jelly	Cook fruit with sugar and lemon juice. Add pectin if needed. Heat till gel stage (65–68° Brix) and Fill in sterilized bottles	6–9 months	Farmer markets, tribal haats, school nutrition schemes
4.	Pickle	Wash and cut the fruit. Then add salt, red chili powder, mustard seeds, fenugreek, oil. Store in glass jars	2–3 months without refrigeration	Farmer markets, tribal haats etc.
5.	Syrup/ Concentrate	Extract the juice. Add sugar, lemon juice and adjust to 68° Brix while heat processing. Bottle and cool	2 weeks without refrigeration and more than 6 months with refrigeration	Mixed with water or soda
6.	Water apple wine or vinegar	Extract the juice. Adjust TSS to 24° Brix while heat processing. Add *yeast* and allow to ferment upto 5-12 days. Filter and Store	6 months	Can be consumed as Light Wines or White Wine. A very promising product for good economic returns

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Promise or Peril? Navigating the Ethical Maze of GM Crops in Modern Agriculture

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Genetically Modified (GM) crops have emerged as a significant innovation in global agriculture, offering potential solutions to challenges such as pest resistance, yield improvement, and climate resilience. However, their adoption is accompanied by complex ethical issues, particularly in the Indian context. This paper examines the ethical dimensions surrounding GM crops, including health and environmental safety, seed patenting, corporate control, farmer autonomy, informed consent, and cultural considerations. It provides a global overview of GM crop adoption, analyzes the status and controversies of GM crops in India—highlighting the recent Supreme Court split verdict on GM mustard—and compares regulatory approaches in different countries. The discussion emphasizes the need for transparent, inclusive, and science-based policymaking that balances innovation with ethical responsibility. The paper concludes by recommending robust public sector research, farmer education, stringent regulatory frameworks, and public engagement as essential pathways for ethically integrating GM crops into Indian agriculture.

Keywords: Genetically Modified Crops, Biosafety, Farmer Autonomy, Seed Patenting, GEAC

Introduction

Genetically Modified (GM) crops are plants whose DNA has been altered using modern biotechnology to introduce desirable traits—such as resistance to pests, tolerance to herbicides, improved nutritional content, or resilience to climate stress. Since their introduction, GM crops have promised solutions to pressing agricultural challenges: higher yields, reduced pesticide use, and adaptation to changing climates. Yet, their adoption has sparked intense ethical debates worldwide, touching on food safety, environmental risks, corporate control, and the rights of farmers.

In India, the conversation around GM crops reached a new milestone in 2024–2025, when the Supreme Court delivered a split verdict on the government's approval for the commercial release of GM mustard, the country's first GM food crop. While one judge quashed the approval citing lack of indigenous studies and environmental concerns, another upheld it, emphasizing the role of scientific expertise and food security. The Court unanimously directed the government to formulate a comprehensive national policy on GM crops, reflecting the urgency and complexity of the issue in India's agricultural and policy landscape. As India stands at a crossroads, the ethical considerations surrounding GM crops are more relevant than ever.

A. Global Overview of GM Crop Adoption

GM crops have been rapidly adopted in several countries since the mid-1990s. Today, over 30 countries cultivate GM crops, with the United States, Brazil, Argentina, Canada, and China leading in terms of area and diversity of crops grown. The most widely grown GM crops globally include soybean, maize (corn), cotton, and canola.

In the USA, over 90% of soybean, maize, and cotton acreage is now planted with GM varieties, reflecting near-universal adoption. Brazil and Argentina have also embraced GM

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technology, especially for soybean and maize. India, despite being the world's fifth-largest GM crop cultivator, has officially approved only Bt cotton, with other crops like GM mustard and Bt brinjal facing regulatory and public resistance.

Country	Area under GM Crops (Mha) (2024)	Major GM Crops	Year of First Adoption
USA	75.4	Soybean, Maize, Cotton	1996
Brazil	53	Soybean, Maize	1998
India	11.2 (Bt Cotton)	Cotton	2002
China	3.0	Cotton	1997

B. GM Crops in India – Status and Scope

India's experience with GM crops is unique. Bt cotton, introduced in 2002, remains the only GM crop officially approved for commercial cultivation. It now covers over 95% of the country's cotton area, helping India become a leading cotton producer. However, the journey beyond cotton has been fraught with controversy.

The most prominent recent debate centers on GM mustard, developed by Delhi University to boost yields and reduce edible oil imports. In 2022, the Genetic Engineering Appraisal Committee (GEAC) granted conditional approval for its environmental release, but the Supreme Court's split verdict in 2024 put its commercial rollout on hold pending further policy formulation and stakeholder consultation. Field trials for other crops like Bt brinjal and GM maize have also faced moratoriums or state-level bans, despite ongoing research and field testing by institutions such as the Indian Council of Agricultural Research (ICAR) and the Department of Biotechnology (DBT).

Farmer groups are divided: some, like the Shetkari Sanghatana in Maharashtra, advocate for GM technology to improve productivity and reduce input costs, while others, including major national and organic farming groups, caution against potential risks to health, environment, and farmer autonomy. The scope for GM crops in India is significant, given challenges like food security, climate variability, and the need for sustainable biofuel sources. However, progress is hampered by regulatory uncertainty, public mistrust, and ongoing legal battles.

C. Ethical Concerns and Controversies

Health & Safety:

A major ethical concern is the potential impact of GM crops on human health. Critics point to the lack of long-term studies on allergenicity and toxicity, especially for food crops like GM mustard and Bt brinjal. Cross-pollination with non-GM varieties raises further questions about unintended exposure and labeling.

Environmental Concerns:

GM crops can affect biodiversity by promoting monocultures and potentially harming non-target organisms, such as beneficial insects and soil microbes. There are documented cases of pests developing resistance to GM traits (e.g., pink bollworm in Bt cotton), which can undermine the technology's effectiveness and ecological balance.

Seed Patenting and Corporate Control:

Most GM seeds are patented by multinational corporations, raising fears of market monopolies and dependency. Farmers often cannot save or reuse GM seeds due to intellectual property (IP) restrictions, leading to increased costs and reduced autonomy. In India, this has fueled debates about food sovereignty and the role of public versus private sector research.

Farmer Autonomy and Social Impact:

The link between GM crops and farmer distress, including suicides, is highly contested. While some studies suggest that Bt cotton has improved incomes, others argue that rising input costs and pest resistance have exacerbated vulnerabilities. Ensuring that farmers are fully informed and have real choices is a recurring ethical demand.

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Informed Consent and Cultural Sentiments: Are farmers and consumers adequately informed about GM technology? The lack of transparent labeling and public engagement undermines informed consent. Additionally, the introduction of GM crops into traditional farming systems has sparked cultural and religious objections, especially in regions with strong food heritage.

D. Legal and Judicial Dimensions

The legal landscape for GM crops in India is shaped by a patchwork of regulations and high-profile court cases. The Supreme Court's 2024 split verdict on GM mustard highlighted deep divisions over biosafety, environmental protection, and procedural transparency.Justice Nagarathna quashed the approval, citing reliance on foreign studies and inadequate indigenous research, while Justice Karol upheld the process, emphasizing expert oversight and food security needs.

The Court directed the government to develop a national GM crop policy through broad stakeholder consultation, underscoring the need for robust, transparent, and science-based regulation. Multiple Public Interest Litigations (PILs), such as those filed by activist Aruna Rodrigues, have called for moratoriums on GM crop releases until comprehensive biosafety protocols are established.

Compared to India's cautious and consultative approach, the United States has a more permissive regulatory regime, with rapid commercialization and limited pre-market testing. The European Union, in contrast, maintains strict precautionary principles, with rigorous risk assessments and widespread bans on GM crop cultivation.

E. Balancing Innovation and Ethics – Way Forward

The path forward requires balancing the promise of biotechnological innovation with ethical imperatives:

- **Strengthen Public Sector R&D:** Institutions like ICAR and the Indian Agricultural Research Institute (IARI) should lead in developing GM crops tailored to India's needs, ensuring that benefits are widely shared and not monopolized by private entities.
- **Transparent, Inclusive Decision-Making:** Policy formulation must involve farmers, scientists, civil society, and state governments, as directed by the Supreme Court. Open-source biotech platforms can democratize access and reduce dependency on patents.
- **Farmer Education and Training:** Empowering farmers with accurate information and training is essential for informed choices and responsible adoption.
- **Robust Regulatory Frameworks:** Strengthen the GEAC's transparency, mandate independent impact assessments, and enforce biosafety protocols in line with international standards such as the Cartagena Protocol and the Indian Biodiversity Act.
- **Mandatory Labeling and Public Awareness:** Clear labeling of GM foods and public engagement campaigns can build consumer trust and respect for choice.
- **Ethical Standards:** Ensure that environmental, health, and social impacts are thoroughly evaluated before commercialization, with mechanisms for redress and accountability.

Conclusion

Genetically Modified crops are neither a panacea nor a peril—they are a tool whose value depends on how society chooses to use them. The ethical challenges they raise—on safety, environment, ownership, and autonomy—demand science-backed, transparent, and inclusive decision-making. As India crafts its national GM crop policy, the focus must remain on food and climate security, but not at the cost of public trust or farmer welfare.

As Dr. Rohini Sreevathsa of ICAR-NIPB aptly puts it, "With the right safeguards and transparent institutions, GM crops can coexist with food safety, ecological stewardship, and farmer choice" The future of Indian agriculture depends on getting this balance right—where innovation serves not just productivity, but also the broader public good.

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Herbal Anesthetics in Aquaculture: A Safer, Greener Alternative to Synthetics

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Herbal anesthetics are emerging as effective and eco-friendly alternatives to synthetic compounds in aquaculture. Derived from plant sources such as clove, peppermint, lavender, and rosemary, these natural anesthetics offer benefits including low toxicity, biodegradability, cost-effectiveness, and minimal residue in fish tissue. With increasing concerns over the environmental and physiological impacts of synthetic anesthetics, herbal options are gaining attention for use in fish handling, transport, and minor procedures. This article explores the types, mechanisms, and advantages of herbal anesthetics, highlighting their potential role in promoting sustainable and safe aquaculture practices.

Keywords: Anesthesia, herbal, Essential oils, Clove Oil, Aquaculture

Introduction

Anesthesia is a substance or drug that causes loss of sensation and awareness. It is primarily used to anesthetize an organism, rendering it insensitive to pain during procedures such as surgery or handling. Anesthesia is a common practice used to improve animal welfare and reduce the negative impacts of stress factors in aquaculture practices.

A suitable anesthetic is that anesthesize the fishes rapidly and quick recovery. An ideal anesthetic should be highly effective, widely available, cost-effective, and exhibit minimal or no toxicity after use. It should not accumulate in fish tissues or pose any adverse effects on humans or animals upon consumption. There are several anesthetics used for treatment of fish, namely Tricaine Methane Sulfonate benzocaine, 2-phenoxyethanol, and metomidate, (a chemical agent) and clove oil, peppermint essential oil, nutmeg essential oil, rosemary essential oil (a natural agent) etc, are used as anesthesia and analgesia (Hoseini et al.,2019). Anesthetic drugs may reduce the movement of fish and stress. During transportation and handling fish feel less pain and become calm. In this situation, they keep the fish immobile but do not disturb the equilibrium of fish. For safety the concentration of anesthesia and duration of exposure are essential. Administering too much anesthesia can be fatal, whereas too little may fail to properly sedate the fish. This controlled practice helps minimize stress and injury, thereby promoting fish welfare in both research and aquaculture settings. The use of anesthesia plays a crucial role in fish care by improving the safety and humaneness of handling and experimental procedures.

Types of anesthetic agents

1. Synthetic anesthesia- The most frequently used synthetic anesthetics include 2 phenoxyethanol, tricaine methane-sulfonate (MS-222), benzocaine, metomidate, etomidate, quinaldine sulfate, propofol, and ketamine hydrochloride. However, some of these agents are costly and may cause stress or side effects like hyperactivity, mucus secretion, and tissue irritation.

2. Natural anesthetics or Herbal anesthetics – Natural or herbal anesthetics are plant-derived substances used to sedate or anesthetize fish during handling, transport, or medical procedures. These alternatives to synthetic anesthetics are gaining popularity due to their eco-friendliness, lower toxicity, biodegradability, and minimal residue risk. Various herbal anesthetics, in the form of essential oils and their constituents, are now being used to anesthetize fish. Various essential oils (EOs) derived from plant parts such as leaves, flowers, buds, stems, and roots.

2.1 Herbal Essential oil-

Herbal essential oils are gaining attention as promising alternatives to synthetic anesthetics in aquaculture. Several studies have examined the anesthetic effects of oils derived from plants such as basil, thyme, mint, rosemary, lavender, citronella, verbena, and camphor across various fish species. In recent years, research has also focused on specific active compounds within these oils-such as eugenol, menthol, myrcene, 1,8-cineole, linalool, limonene, citronellal, thymol, carvacrol, spathulenol, α- and β-pinene, 4-allyl phenyl acetate, and Globulol-for their sedative and anesthetic potential in fish (Aydin and Barbas, 2020). These natural anesthetics may provide a more eco-friendly, affordable, and safer alternative to synthetic agents in promoting fish health and welfare in aquaculture operations.

2.2 Different herbal essential oils as an anesthesia

a. Clove Oil - It is most widely used in aquaculture practices during handling, transportation, breeding etc, (Javahery et al., 2012). its active compound is eugenol which has anesthetic and antibacterial properties. Clove essential oil may be less harmful than 2-phenoxyethanol and MS-222, making it a less expensive and cost-effective option for large-scale use in juvenile *Pterophyllum scalare*.

b. Nutmeg Essential Oil-Nutmeg, primarily produced in Indonesia, Guatemala, and India, has recently gained attention for its essential oil being used as an anesthetic in fish. The key active compounds in nutmeg oil, β-myrcene and β-pinene, possess sedative and anesthetic properties, making it suitable for applications such as fish transportation.

c. Coriander Essential Oil - Coriander Oil (*Coriandrum sativum*), which is derived from coriander plants. Coriander contains the active ingredient linalool used for anesthetic purposes in fish, only a small number of fish species have been CEO studied. Alternative anaesthetics must be evaluated on a variety of fish species since concentration levels can fluctuate between substances and fish species and are also affected by abiotic and biological factors (Haihambo et al., 2024)

d. *Ocimum gratissimum* (Tree basil) Essential Oil- The essential oil contains active terpene compounds such as linalool and methyl chavicol, which have been identified as effective and safe anesthetics for fish (Silva et al., 2012).

e. Lavender Essential Oil- Lavender essential oil, derived mainly from *Lavandula angustifolia*, is gaining attention in aquaculture for its mild sedative and anesthetic effects on fish. Its main active ingredients are linalool and linalyl acetate cause sedative effects. It has been demonstrated that lavender essential oil has an anaesthetic effect on blue dolphin cichlids, convict cichlid fish, *Cyprinus carpio*, European catfish, and rainbow trout (*O. mykiss*) (Yigit et al., 2022).

f. Rosemary Essential Oil- Rosemary essential oil, extracted from *Rosmarinus officinalis*, has been explored in aquaculture for its natural anesthetic and sedative effects. Eucalyptol (1.8-cineole) and alpha-pinene are the primary active components of rosemary essential oil (Bauer et al., 1997). Rosemary essential oil used for anesthesia of *C. carpio* with concentrations from 0.25 to 1 ml/l (Ghazilou and Chenary, 2011).

g. Eucalyptus Essential Oil- Eucalyptus essential oil, derived mainly from *Eucalyptus globulus*, has been studied for its anesthetic properties in aquaculture due to its natural origin and bioactive compounds.The primary active constituent is 1,8-cineole (eucalyptol), which exhibits both sedative and anesthetic effects.

h. Lippia alba (*bushy matgrass*) Essential Oil- Lippia alba as a sedative, and the essential oil derived from this species contains components such as citral, myrcene, linalool, and limonene that have sedative, anxiolytic, and motor relaxant properties. Studies have demonstrated that *Lippia alba* essential oil can be used to safely anesthetize fish such as silver catfish (Cunha et al., 2010).

i. *Cymbopogon citratus* (Lemongrass) Essential Oil - Essential oil from *C. citratus* is known for its immunomodulatory, anti-inflammatory, antiseptic, antimicrobial, and antifungal properties Research on the sedative and anesthetic effect of lemongrass has been done with species such as: freshwater angelfish, Nile tilapia juveniles (Souza et al., 2017).

j. Lemon verbena (*Aloysia triphylla*) Essential Oil - Aloysia triphylla includes substances that have been found to have sedative effects in a variety of species, its active compound is citronellal and geraniol. Sedation symptoms in fish treated with *Aloysia triphylla* extracts include decreased motility (Dos Santos et al., 2017).

k. Peppermint Essential Oil- Peppermint (*Mentha piperita*) essential oil is being increasingly explored in aquaculture for its natural anesthetic and sedative properties. This oil is rich in active compounds, menthol (Aguiar et al., 2023). In aquaculture, peppermint essential oil has gained considerable interest for its strong anesthetic properties. The concentration of 100 µl/L of peppermint essential oil provides adequate deep anesthesia, and it is advisable to utilize a safe concentration range of 10 to 100 µl/L for the transportation of dolphin cichlid fish (Can and Sumer, 2019). Listyaningrum and Hastuti (2023) have demonstrated that menthol can effectively induce anesthesia in common carp.

Advantages of herbal anesthetics over synthetic anesthetics

Herbal anesthetics offer several key advantages over synthetic alternatives in aquaculture, making them promising substitutes as the industry grows:

Ecofriendly – Unlike synthetic anesthetics, which can persist in the environment and harm non-target species through bioaccumulation, herbal anesthetics are typically biodegradable and pose a lower risk of water pollution, supporting a healthier aquatic ecosystem.

Health Benefits: Synthetic anesthetics can harm fish health with repeated use, while herbal alternatives are generally safer and less toxic.

Sustainability: Derived from renewable plant sources, herbal anesthetics require less energy to produce and generate fewer emissions, contributing to a lower environmental impact.

Cost-Effectiveness: Herbal anesthetics are generally more affordable and accessible, particularly for small-scale operations. Lower dosages may be effective, making them an economical choice in the long term.

Conclusion

Herbal anesthetics, primarily in the form of essential oils derived from plants such as basil, thyme, mint, lavender, rosemary, citronella, camphor, and nutmeg, have emerged as promising alternatives to conventional synthetic anesthetics in aquaculture. Active compounds like eugenol, linalool, menthol, thymol, carvacrol, β-myrcene, and β-pinene exhibit effective sedative and anesthetic properties in fish. Compared to synthetic agents such as MS-222, benzocaine, and ketamine, herbal anesthetics offer several key advantages: they are often more environmentally friendly, biodegradable, less toxic, and cost-effective.

Reference:

Aguiar G. A. C. C. D., Carneiro C. L. D. S., Campelo D. A. V., Rusth R. C. T., Maciel J. F. R., Baldisserotto B. & Salaro A. L. (2023). Effects of dietary peppermint (*Mentha piperita*) essential oil on growth performance, plasma biochemistry, digestive enzyme activity, and oxidative stress responses in juvenile Nile tilapia (*Oreochromis niloticus*). *Fishes*. 8(7): 374-382.

Bauer, K., Garbe,D., & Surburg, H. (1997). Common fragrance and flavor materials. Wiley-VCH, Berlin, Germany.

Cunha, M. A., de Barros, F. M. C., de Oliveira Garcia, L., de Lima Veeck, A. P., Heinzmann, B. M., Loro, V. L. & Baldisserotto, B. (2010). Essential oil of Lippia alba: a new anesthetic for silver catfish, Rhamdia quelen. *Aquaculture*, *306*(1-4), 403-406.

Dos Santos, A. C., Junior, G. B., Zago, D. C., Zeppenfeld, C. C., da Silva, D. T., Heinzmann, B. M., & da Cunha, M. A. (2017). Anesthesia and anesthetic action mechanism of essential oils of Aloysia triphylla and Cymbopogon flexuosus in silver catfish (*Rhamdia quelen*). Veterinary anaesthesia and analgesia, 44(1), 106-113.

Ghazilou, A., & Chenary, F. (2011). Evaluation of rosemary oil anesthesia in carp. Online Journal of Veterinary Research, 15(2), 112-118.

Haihambo, W., Gabriel, N. N., Rashidian, G., Iitembu, J. A., Kapula, V. K., & Ukongo, A. N. (2024). The evaluation of anaesthetic efficacy of Coriandrum sativum essential oils in three-spotted tilapia (*Oreochromis andersonii*): a study of fish size and water temperature. Discover Agriculture, 2(1), 57.

Listyaningrum A. & Hastuti S. (2023). Acute Study of the Effect of Peppermint essential oil (*Mentha arvensis*) as Anesthetic Material on the Survival Rate and Blood Profile of Blitar Koi Fish (*Cyprinus carpio*). J. Biochem. Int. 10(1): 67-76.

Souza, C., Baldissera, M., Salbego, J., Lopes, J., Vaucher, R., Mourao, R., Caron, B., Heinzmann, B., Silva, L., & Baldisserotto, B. (2017). Physiological responses of silver catfish to anesthesia withessential oils from two different chemotypes of Lippia alba. Neotropical Ichthyology, 15, e160083.

Yigit, N. O., Metin, S., Didinen, B. I., Didinen, H., & Ozmen, O. (2022). Effect of lavander (*Lavandula angustifolia*) and laurel (Laurus nobilis) essential oils as anesthetics in rainbow trout (Oncorhynchus mykiss). Aquaculture, 557, 738328.

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FLAVOURS IN A DROP: THE GASTRONOMY OF ESSENTIAL OILS

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Food-grade essential oils are emerging as innovative, natural enhancers in contemporary cooking, offering concentrated flavour and aroma in minimal amounts. Derived from plants such as herbs, fruits, and spices through techniques like cold pressing and steam distillation, these oils bring vibrant, clean-tasting profiles to a wide variety of dishes. When used with care, they serve as a healthier alternative to synthetic additives, complementing both sweet and savoury recipes. Many of these oils also contribute functional benefits, including digestive support and antimicrobial effects. Due to their potency, they must be used in tiny doses and chosen with attention to quality and safety standards. This article outlines their extraction methods, safe usage, and creative gastronomy roles, emphasizing how essential oils combine nutrition, flavour, and wellness. From adding depth to main courses to elevating desserts and drinks, they offer a refined and sustainable approach to flavour in modern kitchens.

Keywords: Essential oils, flavor, cold pressing, steam distillation, gastronomy

INTRODUCTION

In today's dynamic culinary landscape, cooking is moving beyond conventional methods to incorporate more nutritious, flavourful, and creative elements. Essential oils, long valued in wellness and aromatherapy, are now making their mark as unique and powerful ingredients in the kitchen. Extracted from herbs, spices, fruits, and flowers, these oils capture the concentrated essence of plants and offer a bold, natural flavour in just a single drop. Each oil delivers a pure and vibrant taste that reflects the true character of its source. With a long shelf life and freedom from preservatives or artificial additives, essential oils align perfectly with clean-label, plant-based, and health-conscious culinary trends. The value of essential oils extends beyond taste. Many possess beneficial properties that support overall well-being. They add precision, elegance, and wellness to every dish capturing the beauty of nature in each drop.

ESSENTIAL OILS

Essential oils are concentrated natural extracts obtained from plants through processes such as steam distillation or cold pressing. Although essential oils are widely known for their roles in aromatherapy, wellness, and cosmetic products, a specific group known as food-grade or culinary essential oils is considered safe for use in cooking when applied with proper care (Angelini et.al, 2021).

STANDARDS FOR USING ESSENTIAL OILS IN FOOD

Essential oils must be completely pure, free from artificial additives or fillers, and clearly labeled for food use or approved as Generally Recognized As Safe (GRAS) by regulatory authorities like the FDA. Due to their strong potency, only a very small amount is required, usually just one or two drops in a recipe.

METHODS OF EXTRACTION

Steam-Based Extraction

This is the most common approach for obtaining essential oils, where steam is passed through plant material, causing the aromatic compounds to evaporate. The vapor, which contains both water and oil, is cooled and separated, resulting in essential oil and floral water (hydrosol). This technique helps retain the plant's original aroma and benefits, though it can be time-intensive and isn't ideal for all plant types.

Mechanical Pressing

Best suited for citrus fruits, this method involves pressing the peels of fruits like oranges and lemons to release their oils. No heat is used, helping maintain the fresh, zesty essence of the fruit. While this technique is simple and economical, it only works well for citrus-based essential oils.

Solvent-Based Extraction

In this method, solvents such as hexane or ethanol dissolve the fragrance compounds from the plant. Once the solvent is removed through evaporation, the remaining substance contains concentrated oil and sometimes waxes or pigments. It's highly effective for fragile flowers, but the risk of solvent residue makes it less suitable for edible or therapeutic uses unless purified properly (Aziz et.al, 2018).

Other techniques such as supercritical extraction, microwave assisted extraction and ultrasound assisted extraction.

EXAMPLES

Each oil carries the distinct and intense flavour of its original plant source. Lemon oil, extracted from the peel, provides a fresh and bright citrus aroma. Basil oil offers the characteristic sweet and peppery taste of the herb, while cinnamon bark oil delivers a warm and spicy richness suited for sweet preparations. These essential oils are much more concentrated than dried herbs or traditional extracts. A single drop of oregano oil, for instance, can match the strength of one to two teaspoons of dried oregano. Their purity and strength make culinary essential oils a practical and flavourful choice for enhancing a wide range of dishes in modern kitchens. Orange essential oil aids digestion by relieving bloating, soothing cramps, and promoting enzyme activity. It has antimicrobial and anti-inflammatory activity (Fig.1).

Fig.1 Preparation and benefits of orange essential oil

SAFETY GUIDELINES OF ESSENTIAL OIL IN GASTRONOMY

Essential oils are extremely concentrated and must be used cautiously in food preparation. It is crucial to choose only those specifically marked as food-grade or safe for consumption, as oils made for external use or aromatherapy are not suitable for eating. Since their flavour and potency are intense, only a very small amount—usually a single drop—is needed. Using more than necessary can not only overpower the flavour of a dish but may also cause irritation to the digestive system. Some essential oils, including eucalyptus, camphor, wintergreen, and pennyroyal, are not considered safe to consume and should be avoided entirely. Just like common allergens, certain oils may trigger allergic responses in sensitive individuals. Those who are pregnant, breastfeeding, or taking medications should consult a healthcare provider before incorporating essential oils into their diet.

ADVANTAGES

- Intense and pure flavor
- Long Shelf-life

- Natural and Additive Free
- Health and Wellness benefits
- Supports Plant-Based and Functional Diets

CREATIVE CULINARY APPLICATIONS

- **Baking**: Add orange or lemon oil to cakes, muffins, or cookies for a fragrant citrus twist.
- **Chocolate & Confectionery**: Pair peppermint or cinnamon oil with dark chocolate truffles, or rose oil in icing for a floral touch.
- **Cocktails & Beverages**: A drop of lime or cardamom oil adds depth to mocktails, infused waters, or herbal teas.
- **Savory Recipes**: Use basil, rosemary, thyme, or black pepper oil in marinades, sauces, or soups for bold herbal notes.
- **Salads & Dips**: Mix herb oils with olive oil and vinegar for quick vinaigrettes, or blend into hummus and yogurt dips for added flair.

CONCLUSION

In a world where taste, health, and sustainability matter more than ever, culinary essential oils offer an exciting way to cook boldly, naturally, and creatively. These tiny drops hold immense potential—not just to flavour our food, but to elevate our cooking into an aromatic, wellness-enhancing experience. From gourmet chefs to mindful home cooks, many are discovering that a single drop of essential oil can bring bold flavour without complexity—proving that in the kitchen, less can truly be more.

REFERENCES

1. Angelini, E., & Dziuba, L. (2021). Essential Oils. In *Handbook of Molecular Gastronomy* (pp. 265-274). CRC Press.
2. Valdivieso-Ugarte, M., Gomez-Llorente, C., Plaza-Díaz, J., & Gil, Á. (2019). Antimicrobial, antioxidant, and immunomodulatory properties of essential oils: A systematic review. *Nutrients*, *11*(11), 2786.
3. Aziz, Z. A., Ahmad, A., Setapar, S. H. M., Karakucuk, A., Azim, M. M., Lokhat, D., ... & Ashraf, G. M. (2018). Essential oils: extraction techniques, pharmaceutical and therapeutic potential-a review. *Current drug metabolism*, *19*(13), 1100-1110.

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Fly Ash: From Industrial Waste to Sustainable Resource

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Fly ash, a byproduct of coal combustion, has evolved from being a disposal challenge to becoming a valuable resource in numerous industrial sectors. This comprehensive article delves into the genesis of fly ash, its chemical and physical characteristics, and its wide-ranging applications, particularly in the realms of construction and agriculture. In addition, the article discusses associated environmental concerns and emphasizes the need for sustainable management practices. The transformation of fly ash from waste to resource epitomizes the principles of a circular economy, reducing the strain on natural resources and minimizing environmental footprints.

Introduction

Throughout the 20th and early 21st centuries, coal remained a dominant source of energy fueling industrial growth and electricity generation. However, this heavy reliance on coal brought with it significant environmental challenges, primarily in the form of coal combustion byproducts. Among these, fly ash emerged as a prominent and problematic residue. Characterized as a fine, powdery substance, fly ash was initially seen as an environmental burden due to its massive generation and the difficulty associated with its safe disposal.

Large volumes of fly ash were deposited in landfills or ash ponds, leading to potential contamination of surrounding soil and water bodies. As environmental concerns intensified and research initiatives expanded, a shift in perception began. The scientific community started to recognize the potential of fly ash, owing largely to its pozzolanic properties and its composition, which could be harnessed in a range of industrial applications.

This transformation signifies a broader trend in modern waste management and sustainable development. Materials once deemed hazardous or useless are now being repurposed, aligning with the ethos of a circular economy. The growing body of research and the development of innovative applications have propelled fly ash into the spotlight as a sustainable resource. This article seeks to provide an in-depth examination of fly ash, its properties, and its numerous applications, while also addressing environmental considerations and highlighting the importance of responsible utilization and management.

Origin and Formation of Fly Ash: Fly ash is produced during the combustion of pulverized coal in thermal power plants. When coal is burned, mineral impurities such as clay, quartz, and shale melt and fuse. As the molten material cools, it solidifies into spherical glassy particles that are carried away with the flue gases. These particles are collected using electrostatic precipitators or baghouse filters, resulting in fly ash.

The characteristics of fly ash depend on several factors, including the type of coal used, combustion conditions, and the methods employed for collection and storage. Typically, fly ash is a fine, grey powder resembling Portland cement in texture. It is composed mainly of silica, alumina, iron oxide, and calcium oxide, with trace amounts of other elements.

Properties and Classification

Fly ash is broadly classified into two categories based on its chemical composition, as defined by the American Society for Testing and Materials (ASTM C618):

1. **Class C Fly Ash (High-Calcium Fly Ash)**

Derived primarily from sub-bituminous and lignite coals, Class C fly ash contains more than 20% calcium oxide (CaO). It possesses both pozzolanic and self-cementing properties, meaning it can form cementitious compounds when mixed with water without requiring an external activator.

2. **Class F Fly Ash (Low-Calcium Fly Ash)**

Obtained mainly from the combustion of bituminous and anthracite coals, Class F fly ash contains less than 10% CaO. It is pozzolanic in nature and requires a source of calcium hydroxide, such as Portland cement, to initiate the cementitious reaction.

Physical Properties

- **Particle Size:** Typically ranges from less than 1 micron to 100 microns.
- **Specific Gravity:** Generally between 2.1 to 2.6.
- **Surface Area:** Higher surface area contributes to increased pozzolanic activity.
- **Color:** Usually grey or tan, depending on its chemical composition.

The pozzolanic activity, fineness, and particle size distribution significantly influence the usability of fly ash in various applications. The finer the particles, the better the workability and performance in cementitious materials.

Applications in Construction

The construction industry is the largest consumer of fly ash, utilizing it as a supplementary cementitious material to improve the quality and durability of concrete and reduce environmental impacts.

1. Cement Replacement

Fly ash can replace 15-30% of Portland cement in concrete mixes. This substitution not only reduces greenhouse gas emissions associated with cement production but also enhances concrete properties, such as improved workability, lower heat of hydration, and increased durability.

2. Concrete Admixtures

Fly ash enhances resistance to sulfate attack, reduces alkali-silica reactivity, and lowers permeability. This makes it ideal for structures exposed to aggressive environments, such as marine and wastewater infrastructure.

3. Road Construction

Fly ash is used in sub-base and base courses, embankments, and soil stabilization. It improves the bearing capacity of soils, reduces shrink-swell potential in clayey soils, and offers long-term durability.

4. Bricks and Blocks

Fly ash bricks are made by mixing fly ash with lime and gypsum. These bricks offer advantages such as lighter weight, superior strength, and lower environmental impact compared to traditional clay bricks. They also utilize less water and energy during production.

5. Grout and Mortar

Fly ash is used in grout and mortar to improve workability and reduce shrinkage. It fills voids effectively and contributes to enhanced structural integrity.

Applications in Agriculture

The utility of fly ash extends beyond construction and finds a valuable niche in agriculture, particularly as a soil amendment and nutrient source.

1. Soil Amendment

Fly ash improves soil texture and structure, especially in heavy clay and sandy soils. It enhances water retention, aeration, and drainage, thereby promoting better root development and plant growth.

2. Nutrient Supply

Fly ash contains trace elements like calcium, magnesium, potassium, and micronutrients such as zinc, copper, and boron, which are essential for plant growth. These nutrients can complement chemical fertilizers.

3. pH Adjustment

In regions with acidic soils, the alkaline nature of fly ash can help neutralize soil acidity, creating a more favorable environment for crop growth.

4. Waste Management in Agriculture

Fly ash can be utilized in composting processes and waste stabilization, improving the hygienic quality and nutrient value of compost.

Environmental Considerations

Despite its numerous benefits, the management of fly ash must be undertaken with caution due to potential environmental hazards.

1. Heavy Metal Leaching

Fly ash may contain trace levels of heavy metals such as arsenic, lead, cadmium, and mercury. If not properly managed, these can leach into soil and groundwater, posing serious health risks.

2. Airborne Dust

Fine fly ash particles can become airborne, contributing to air pollution and respiratory issues among workers and nearby populations.

3. Landfill Issues

Disposal of unutilized fly ash in landfills can lead to contamination of surrounding ecosystems. Moreover, fly ash occupies valuable land space that could be used for other purposes.

Mitigation Measures

- **Proper Storage:** Fly ash should be stored in lined ash ponds or silos to prevent leaching and air dispersion.
- **Dust Suppression:** Use of water sprays, covers, and enclosed transport systems to minimize dust emissions.
- **Regular Monitoring:** Conduct leaching tests and environmental monitoring to ensure compliance with safety standards.
- **Regulatory Frameworks:** Governments and regulatory bodies have established standards and guidelines for the safe handling, transportation, and utilization of fly ash.

Conclusion

The evolution of fly ash from an industrial byproduct to a valuable resource is a compelling example of sustainable innovation. Its wide-ranging applications in construction and agriculture contribute significantly to resource conservation, environmental protection, and economic efficiency. By replacing traditional materials such as Portland cement and chemical fertilizers, fly ash helps reduce carbon emissions and conserves non-renewable resources.

However, for fly ash to be a truly sustainable solution, it must be managed responsibly. This includes stringent monitoring of its environmental impact, adherence to regulatory frameworks, and continuous research into safe and effective utilization methods. Advancements in technology and increased public-private collaboration can further enhance the scope of fly ash applications.

In conclusion, fly ash stands as a testament to the power of innovation and environmental stewardship. It embodies the core principles of the circular economy, transforming waste into wealth and contributing to a more sustainable and resilient future. As we move toward greener industrial practices, the story of fly ash serves as both a blueprint and an inspiration for the responsible use of industrial byproducts.

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Zero Budget Natural Farming: Key Components, Challenges and the Future of Sustainable Agriculture

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Introduction

ZBNF or Zero Budget Natural Farming is a farming approach that focuses on growing crops without using outside inputs like fertilizer and pesticides. Green manure and cow dung are examples of natural resources. In addition to enabling low production costs, it guarantees chemical-free produce, which supports sustainable agriculture in India. This approach holds promising potential for addressing farmer debt, environmental degradation, and food security.

The founder of Zero Budget Natural Farming is Subhash Palekar. In Karnataka throughout the 1990s, he promoted ZBNF methods. The objective was to overcome the negative impacts of chemical use and intense irrigation under intensive farming practices.

Key Components of Zero Budget Natural Farming

ZBNF is built on four essential pillars that work together to restore soil health and improve crop productivity without external inputs:

1. **Bijamrita (Seed Treatment):** Seeds are treated with a natural formulation made using cow dung, cow urine, neem leaves and other plant extracts. This protects seeds from diseases and encourages healthy germination.
2. **Jiwamrita (Soil Enricher):** A fermented microbial culture prepared from cow dung, cow urine, jaggery, pulse flour and clean soil. It revives soil fertility by enhancing beneficial microbial activity and nutrient availability.
3. **Acchadana (Mulching):** The soil is covered with organic residues like crop waste or cover crops, which conserves moisture, suppresses weeds, and improves soil nutrient content through decomposition.
4. **Waaphasa (Soil Aeration and Moisture):** Ensuring that soil has both adequate air and moisture for optimal root growth, enhancing water retention and nutrient uptake, especially crucial during dry periods.

Principles of Zero Budget Natural Farming (ZBNF)

1. Elimination of External Inputs

- No chemical fertilizers or pesticides.
- No dependence on purchased inputs.

2. Desi Cow-Based Farming

- Indigenous cows are central to ZBNF.
- Use of cow dung and cow urine for:
  - **Jeevamrutha** (soil tonic)
  - **Beejamrutha** (seed treatment)

3. Soil Microbial Activity

- Promotes microbial diversity and soil health.
- Microbes enhance nutrient availability and crop growth.

4. Natural Resource Management

- Emphasis on local resources: soil, water, plant residues.
- Encourages low-cost farming with minimal environmental impact.

5. Whapasa (Moisture-Air Balance)

- Advocates for maintaining moisture and aeration in the soil.
- Avoids excessive irrigation.

6. Mulching (Acchadana)

- Use of crop residues and organic matter to:
  - Protect soil

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- Conserve moisture
- Suppress weeds

7. Diverse and Mixed Cropping Systems

- Promotes polyculture (multiple crops on the same field).
- Enhances ecological balance and soil fertility.

8. No Ploughing, No Tillage (in some versions)

- Minimal disturbance of soil to preserve microorganisms.

Benefits of Zero Budget Natural Farming

1. **Cost Reduction:** By eliminating the need for chemical inputs, farmers save significantly on seed, fertilizer, pesticide and irrigation costs. This reduction in input expenses can help relieve the pervasive farmer debt crisis.
2. **Environmental Sustainability:** ZBNF reduces water use by up to 60%, lowers methane emissions through soil aeration, conserves soil biodiversity and prevents chemical pollution in land and water systems.
3. **Healthier Food Production:** Producing chemical-free crops contributes to safer food consumption, potentially lowering health risks associated with pesticide residues.
4. **Soil Health Improvement:** The natural inputs enhance microbial diversity and soil organic carbon, improving fertility and resilience
5. **Resilience to Climate Change:** By promoting biodiversity, moisture retention, and low external input dependency, ZBNF prepares farms to better withstand climate variability

Challenges in Adoption and Sustainability

1. **Yield Concerns:** Some studies and farmers have reported declining yields after initial years of practice, necessitating more scientific validation of ZBNF's productivity claims.
2. **Scientific Debate:** Experts caution that replacing all conventional farming with ZBNF without adequate research could reduce overall crop production and jeopardize food security.
3. **Transition Period:** Farmers face an adaptation curve shifting from conventional to zero-budget methods; knowledge gaps and initial training needs can hinder widespread adoption
4. **Local Cow Breeds Dependency:** The method relies heavily on indigenous cow dung and urine, but maintaining these breeds poses practical challenges for many farmers.
5. **Market Access:** Limited organic certification and marketing infrastructure may decrease incentives for farmers to engage fully in ZBNF.
6. **Policy and Funding:** Government support and consistent funding are critical, although currently limited in some regions, for training, subsidies, and research

Key Government Support and Policies for ZBNF

1. **National Mission on Natural Farming:** Launched by the central government, this mission promotes ZBNF by providing financial assistance, training, and extension services to farmers. For example, direct benefit transfers (DBT) offer one-time assistance of Rs. 2,000 per hectare for purchasing necessary tools and inputs like liquid manure drums and botanical extract preparation kits.
2. **State-Level Initiatives:** States like Andhra Pradesh have spearheaded large-scale adoption, aiming to transition millions of farmers and millions of hectares of farmland to 100% chemical-free ZBNF practices by 2024. Andhra Pradesh offers financial incentives and

extensive training programs to support farmers during the transition.

3. **Paramparagat Krishi Vikas Yojana (PKVY):** This scheme encourages organic and natural farming practices, complementing ZBNF goals by promoting cluster-based organic farming with government subsidies and infrastructure support.
4. **Capital Investment Subsidy Scheme (CISS):** Financial assistance is provided to state governments and agencies to improve soil health through natural farming, enabling investments in bio-input production and distribution infrastructure.
5. **Research and Extension Support:** The government funds research to validate and improve ZBNF techniques, while extension services aim to raise awareness, provide technical know-how, and build local capacity among farmers.
6. **Budget Allocations:** In recent budgets, substantial funds have been earmarked to promote organic and natural farming systems, reflecting policy commitment to sustainable agriculture and farmer welfare.
7. **Collaborations and Partnerships:** Several states collaborate with universities, NGOs, and international organizations to popularize ZBNF, ensuring knowledge dissemination and addressing practical challenges faced by farmers.

The Future of Sustainable Agriculture and ZBNF's Role

Sustainable agriculture is essential in feeding the world's growing population while conserving natural resources and mitigating climate change. ZBNF, by reducing external inputs and enhancing natural ecosystems within farms, aligns well with the global vision of eco-friendly and resilient farming systems. Innovative approaches, including precision agriculture, regenerative farming, and the integration of biotechnology, complement ZBNF's natural practices in paving the way toward sustainability. Further research, policy support, modern infrastructure, and farmer education will be vital to scale up ZBNF efficiently. ZBNF represents a conscious return to nature-based farming combined with scientific understanding to reclaim soil vitality and economic viability for farmers. If the challenges are met with collaborative efforts, ZBNF could become a cornerstone of sustainable agriculture that empowers small farmers, protects the environment, and ensures food security. Its success will depend on continued innovation, validation, and inclusive support for the farming community worldwide.

Conclusion – Zero Budget Natural Farming (ZBNF)

Zero Budget Natural Farming offers a sustainable, eco-friendly and cost-effective alternative to conventional agriculture. Rooted in traditional Indian practices, it reduces dependency on external inputs by utilizing locally available natural resources like cow dung, cow urine, and organic matter. ZBNF not only enhances soil fertility and improves microbial health, but also supports resilient farming systems that can withstand climate variability. With its focus on low-cost inputs, minimal water use, and natural pest control, ZBNF empowers small and marginal farmers, reduces debt burden, and contributes to food security and environmental conservation. By promoting harmony between nature and agriculture, ZBNF stands as a promising model for future-ready, regenerative farming in India and beyond.

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Nanotechnology in Agriculture: Enhancing Soil Health and Crop Productivity

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Introduction

Nanotechnology has emerged as a transformative tool in modern agriculture, offering new approaches to enhance soil health, nutrient-use efficiency and crop productivity. By utilizing engineered nanomaterials and nano-based formulations, this technology offers precise, efficient, and environmentally sustainable solutions to some of the pressing challenges in farming. Agriculture faces multiple challenges in the 21st century, including declining soil fertility, climate change, increasing population demands and overuse of agrochemicals. Traditional methods are proving insufficient to meet global food security goals. Nanotechnology, involving materials at the scale of 1 to 100 nanometers, offers a promising alternative due to its unique properties. In agriculture, nanotechnology can play a vital role in improving soil health, nutrient availability and crop yield while reducing environmental degradation.

Fundamentals of Nanotechnology

Nanotechnology involves the manipulation and application of materials at the nanoscale. These materials, known as nanoparticles, exhibit unique physical and chemical characteristics, such as high surface area, increased reactivity and enhanced solubility. Common nanomaterials used in agriculture include nano-silica, nano-clay, carbon nanotubes, silver nanoparticles and nano-formulations of fertilizers and pesticides. Techniques like sol-gel processing, chemical vapor deposition and green synthesis are employed for nanoparticle production.

Applications in Soil Health Management

1. **Nano-fertilizers**: Nano-formulations of nitrogen, phosphorus and potassium can enhance nutrient availability and uptake. These fertilizers release nutrients in a controlled manner, improving efficiency and reducing leaching losses.
2. **Soil Amendment**: Nano-clays and nano-calcium carbonate help improve soil structure, water retention and aeration. They also help in stabilizing pH and reducing metal toxicity.
3. **Remediation of Contaminated Soils**: Nanoparticles can immobilize heavy metals and degrade organic pollutants, thus detoxifying the soil.
4. **Soil Moisture Retention**: Nanopolymers and hydrogels improve the water-holding capacity of soils, particularly in arid and semi-arid regions.

Applications in Crop Productivity

1. **Nano-pesticides**: These are more effective than conventional pesticides due to their targeted delivery, reduced dosage and sustained release. They reduce harm to non-target organisms and the environment.
2. **Nano-herbicides and Fungicides**: Help in managing weeds and plant diseases more efficiently.
3. **Growth Regulators**: Nanocarriers can deliver hormones like gibberellins and cytokinins directly to plant tissues, promoting better growth and stress tolerance.
4. **Seed Treatment**: Nanocoating of seeds can enhance germination rates, protect against pathogens, and improve seedling vigor.

Nanotechnology and Nutrient-Use Efficiency (NUE)

Nanotechnology has emerged as a transformative tool in agriculture, particularly in enhancing Nutrient-Use Efficiency (NUE). Traditional fertilizers often suffer from issues such as nutrient losses through volatilization, leaching or runoff, resulting in lower efficiency and environmental harm. Nanotechnology addresses these challenges in several ways:

1. **Targeted Delivery**: Nano-fertilizers are engineered to deliver nutrients directly to the root zone, ensuring minimal loss and maximizing nutrient uptake by plants.
2. **Reduced Volatilization and Leaching**: Encapsulation technologies and slow-release mechanisms in nano-formulations reduce the chances of nutrient loss due to volatilization or leaching, making fertilization more sustainable.
3. **Enhanced Absorption**: The nano-size of these fertilizers allows for greater surface area and better interaction with plant roots, enhancing nutrient absorption.
4. **Improved Synchrony**: Nanotechnology enables better timing in nutrient release, synchronizing nutrient availability with plant demand. This precision minimizes wastage and boosts crop productivity.

Impact on Soil Microbiology and Ecosystem Health

Nanotechnology also impacts the biological dimension of soil health. The integration of nanomaterials in agriculture has both potential benefits and risks for soil microbial communities:

1. **Positive Effects**: Nanomaterials like nano-zeolites and nano-clays provide niches that support microbial colonization. This boosts microbial activity, crucial for nutrient cycling and soil fertility.
2. **Microbial Balance**: Certain nano-formulations include beneficial bio-inoculants that encourage the growth of nitrogen-fixing bacteria and phosphate-solubilizing microorganisms. These symbiotic microbes play a key role in enhancing soil fertility.
3. **Potential Risks**: While many nanomaterials are beneficial, some such as silver nanoparticles—can be harmful to beneficial soil organisms if used excessively. These particles can disrupt microbial diversity and interfere with soil biochemical processes.

A cautious approach, informed by scientific research, is essential to avoid adverse impacts on soil ecosystems.

Advantages of Nanotechnology in Agriculture

Nanotechnology offers a multitude of advantages for modern agriculture, including:

- **Increased Efficiency**: Nano-agrochemicals enhance the efficacy of fertilizers and pesticides by increasing their stability, solubility, and bioavailability.
- **Sustainability**: Reduced use of agro-inputs leads to lower carbon footprints and minimizes environmental pollution.
- **Stress Management**: Nano-formulations can improve plant resistance to biotic and abiotic stresses such as pathogens, drought, and salinity.
- **Cost-Effectiveness**: Though initial costs may be higher, nano-fertilizers reduce the need for repeated applications, ultimately lowering total input costs.

Risks, Limitations and Ethical Concerns

Despite the numerous advantages, nanotechnology in agriculture is not without its limitations and concerns:

1. **Toxicity**: Prolonged exposure to certain nanoparticles can accumulate in plant tissues, posing risks to human and animal health.
2. **Regulatory Gaps**: The absence of clear, enforceable regulations on nano-agriculture creates uncertainty for both producers and consumers.
3. **Environmental Concerns**: Nanoparticles may affect non-target organisms and disrupt aquatic and terrestrial ecosystems.
4. **Public Perception**: Lack of awareness and understanding among farmers and

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consumers may hinder the widespread adoption of nano-agricultural products.

Future Perspectives and Research Needs

To fully leverage the potential of nanotechnology in agriculture, several future directions should be pursued:

1. **Green Nanotechnology**: Emphasizing eco-friendly synthesis of nanoparticles using plant-based or microbial methods can reduce toxicity and environmental impact.
2. **Integration with Precision Agriculture**: Combining nano-sensors with GPS, AI, and data analytics can provide real-time information on plant and soil health, enabling precision interventions.
3. **Tailored Solutions**: Developing region-specific and crop-specific nano-formulations will enhance the effectiveness of these technologies.
4. **Capacity Building**: Farmer education and training programs are essential for the safe and effective use of nano-agrochemicals.
5. **Policy Framework**: Governments should establish clear guidelines, safety protocols, and quality control measures to regulate the use of nanotechnology in agriculture.

Conclusion

Nanotechnology has the potential to transform agriculture by enhancing nutrient-use efficiency, improving soil health, and increasing crop productivity. With its ability to deliver nutrients more precisely, reduce agrochemical use, and support sustainable farming practices, it aligns well with the goals of modern agriculture. However, realizing its full potential requires addressing the associated risks through comprehensive research, robust regulatory mechanisms, and effective outreach programs. If adopted judiciously and ethically, nanotechnology could indeed become a vital component in the future of sustainable agriculture.

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Integrated Nutrient Management for Enhancing Soil Fertility and Crop Yield

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Introduction

Integrated Nutrient Management (INM) is a holistic approach that combines the use of chemical fertilizers, organic manures and biofertilizers to optimize crop productivity while sustaining soil health. Agricultural sustainability hinges on maintaining soil fertility and achieving optimal crop productivity. However, the indiscriminate use of chemical fertilizers over the past decades has led to several problems, including nutrient imbalances, soil degradation and environmental pollution. Integrated Nutrient Management (INM) presents a viable solution by combining different nutrient sources to enhance soil fertility and improve crop yields sustainably. INM aims to balance nutrient supply through the synergistic use of organic, inorganic and biological resources.

Concept of Integrated Nutrient Management (INM)

INM is defined as the judicious application of chemical fertilizers along with organic manures and biofertilizers to achieve sustainable crop production. The primary objective is to maintain or improve soil fertility while reducing dependency on chemical inputs. The key principles of INM include:

- Balanced fertilization based on crop demand
- Site-specific nutrient management
- Utilization of locally available resources
- Conservation of soil and environmental health

Role of Organic Manures and Compost

Organic manures, such as farmyard manure (FYM), compost, green manure and crop residues, are vital components of INM. They improve soil structure, water-holding capacity and microbial activity. FYM and compost increase soil organic matter, which enhances nutrient retention and availability. Green manures, such as Dhaincha and Sunhemp, contribute nitrogen and organic carbon to the soil. Organic manures also buffer soil pH and improve nutrient cycling, making them essential for long-term fertility.

Use of Inorganic Fertilizers in INM

While organic inputs are essential, they alone may not meet the high nutrient demand of modern high-yielding crop varieties. Inorganic fertilizers, such as urea, DAP, MOP and SSP, provide nutrients in readily available forms. In INM, the role of chemical fertilizers is to supplement the nutrient supply from organic sources. Balanced fertilization, guided by soil testing and crop requirements, helps in maximizing nutrient-use efficiency and minimizing losses. Site-specific nutrient management techniques, such as the use of decision support tools and nutrient recommendation charts, are integral to efficient fertilizer use in INM.

Biofertilizers and Their Role in INM

Biofertilizers are preparations containing living microorganisms that fix atmospheric nitrogen, solubilize phosphorus, and decompose organic matter. Common biofertilizers include:

- **Rhizobium** for legumes (nitrogen fixation)
- **Azospirillum** and **Azotobacter** for cereals and vegetables
- **Phosphate-Solubilizing Bacteria (PSB)**
- **Mycorrhizal fungi** that enhance phosphorus and micronutrient uptake
- **Blue-Green Algae (BGA)** and **Azolla** in rice cultivation

Incorporating biofertilizers in INM not only enhances nutrient availability but also improves soil biological activity, contributing to better root development and crop growth.

Soil Health Improvement through INM

Soil health refers to the continued capacity of soil to function as a living ecosystem that sustains plants, animals, and humans. INM contributes to improved soil health by:

- **Physical Improvement**: Enhancing soil texture, reducing compaction and increasing porosity
- **Chemical Improvement**: Maintaining optimal pH and improving cation exchange capacity
- **Biological Improvement**: Increasing microbial biomass, enzymatic activity and organic matter content

Regular incorporation of organic matter enhances the nutrient-buffering capacity of soils, making nutrients more readily available to plants over time.

Effect of INM on Crop Productivity

Numerous field trials and research studies have demonstrated the positive impact of INM on crop yield and quality. For example:

- In rice-wheat systems, combining 50% recommended dose of fertilizers (RDF) with FYM and biofertilizers improved grain yield by 15–20%.
- In maize, INM treatments resulted in better root development, higher nutrient uptake and improved biomass accumulation.
- Leguminous crops showed enhanced nodulation and nitrogen fixation with integrated use of Rhizobium and organic manure.

The synergistic effect of multiple nutrient sources ensures a steady and balanced nutrient supply throughout the crop growth stages.

Environmental Benefits of INM

The environmental benefits of INM are significant and include:

- **Carbon Sequestration**: Organic manures increase soil organic carbon levels, contributing to carbon storage.
- **Reduced Nutrient Leaching**: Slow-release of nutrients from organic sources reduces the risk of nitrate leaching and water pollution.
- **Lower Greenhouse Gas Emissions**: Rational use of nitrogen fertilizers reduces nitrous oxide emissions.
- **Soil Biodiversity Conservation**: Promotes microbial diversity and biological pest control

INM practices contribute to climate-smart agriculture by promoting resource-use efficiency and environmental stewardship.

Challenges in Adoption of INM

Despite its benefits, INM adoption faces several challenges:

- **Availability and Quality**: Limited and inconsistent availability of organic manures and biofertilizers
- **Lack of Awareness**: Farmers often lack knowledge of proper application methods and benefits
- **Economic Constraints**: Higher labor costs for preparation and application of organics
- **Extension Gaps**: Weak linkages between research institutions and farmers
- **Policy Support**: Need for incentives and subsidies to promote organic and bio-based inputs

Strategies for Effective Implementation

To overcome these challenges, the following strategies are recommended:

- **Capacity Building**: Training farmers on INM practices through field demonstrations and extension services
- **Resource Mobilization**: Promoting community-based composting units and vermicomposting
- **Subsidies and Incentives**: Financial support for organic input production and distribution
- **Use of ICT Tools**: Mobile apps and decision support systems for nutrient recommendation
- **Policy Interventions**: Integration of INM in government fertilizer policies and schemes

Future Prospects and Research Needs

The future of INM lies in innovation and contextual adaptation. Research areas that need attention include:

- **Precision INM**: Use of GIS, remote sensing and soil sensors to fine-tune nutrient applications
- **Nano-fertilizers and Liquid Biofertilizers**: Efficient delivery systems to reduce nutrient losses
- **Crop and Site-Specific Recommendations**: Tailoring INM packages based on local conditions
- **Integrated Crop Management (ICM)**: Combining INM with pest, water and residue management
- **Long-Term Monitoring**: Studying the cumulative effects of INM on soil carbon stocks and productivity

Conclusion

Integrated Nutrient Management offers a balanced, efficient and sustainable approach to maintaining soil fertility and enhancing crop yields. By leveraging the strengths of organic, inorganic, and biological sources of nutrients, INM ensures a holistic improvement in soil health and agricultural productivity. While challenges persist, strategic interventions in research, policy, and farmer education can drive the adoption of INM at scale. Embracing INM is a step forward in achieving sustainable and climate-resilient agriculture.

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Enriched Biochar: A Potential Tool to Enhance Nutrient-Use Efficiency

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Nutrient-use efficiency (NUE) is a critical factor in sustainable agriculture, influencing both crop productivity and environmental impact. Biochar, a carbon-rich byproduct of biomass pyrolysis, has shown promise in improving soil fertility and nutrient retention. When enriched with nutrients or microbial inoculants, biochar transforms into "enriched biochar," further enhancing its agronomic potential. This paper explores the preparation, mechanisms and application of enriched biochar as a tool to improve nutrient-use efficiency, soil health and crop productivity. It also highlights the environmental benefits, limitations and future research needs to advance the widespread adoption of enriched biochar in agriculture.

Introduction

Modern agriculture is challenged by declining soil fertility, reduced crop productivity and low nutrient-use efficiency (NUE). These issues result in increased use of chemical fertilizers, which contributes to environmental pollution and depletes non-renewable resources. Improving NUE is imperative for enhancing agricultural sustainability. Among various soil amendments, biochar has emerged as a promising material due to its multifunctional properties. Biochar is a stable, carbon-rich material produced from the pyrolysis of organic biomass in limited oxygen. When biochar is treated or "enriched" with essential nutrients or microbial inoculants, it becomes a powerful tool for improving NUE. Enriched biochar holds potential not only to boost crop yields but also to improve soil health and contribute to climate change mitigation.

Concept and Characteristics of Enriched Biochar

Enriched biochar refers to biochar that has been supplemented or loaded with nutrients, organic matter, or beneficial microbes. The enrichment process involves soaking or mixing biochar with compost, inorganic fertilizers (NPK), or microbial cultures to improve its nutrient content and biological activity. The resulting material acts as a nutrient reservoir and microbial habitat in the soil.

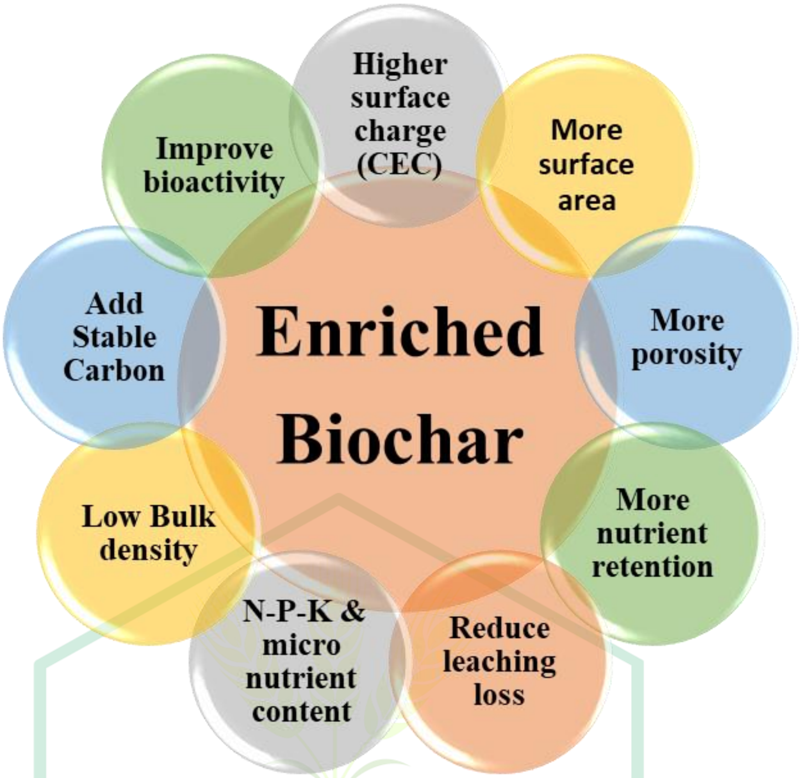
Key characteristics of enriched biochar include:

- **High Porosity and Surface Area:** Facilitates nutrient retention and microbial colonization.
- **Enhanced Cation Exchange Capacity (CEC):** Increases the soil's ability to hold positively charged nutrients.
- **Buffering Capacity:** Helps regulate soil pH and nutrient availability.
- **Improved Water Retention:** Retains moisture, enhancing drought resistance.

Mechanisms Enhancing Nutrient-Use Efficiency

Enriched biochar enhances NUE through various interrelated mechanisms:

1. **Nutrient Adsorption and Retention:** The porous structure of biochar allows it to adsorb and hold nutrients such as ammonium, nitrate and phosphate. This minimizes nutrient leaching, making them more available to plants over time.
2. **Improved Soil pH and CEC:** Enriched biochar, particularly when applied to acidic soils, raises pH levels, making nutrients more



available. Its high CEC supports nutrient exchange between the soil and plant roots.

3. **Slow-Release Nutrient Behavior:** Nutrients stored in biochar are released gradually, synchronized with crop demands. This reduces the need for frequent fertilizer applications.
4. **Promotion of Beneficial Microbial Activity:** Enriched biochar serves as a niche for beneficial microbes, including nitrogen-fixing bacteria and phosphate-solubilizing microorganisms. These microbes enhance nutrient mineralization and mobilization.
5. **Reduction of Nutrient Losses:** Biochar reduces ammonia volatilization and nitrous oxide emissions from nitrogen fertilizers, improving overall efficiency.

Types of Enrichments and Materials Used

Enriched biochar can be produced using different enrichment agents depending on the specific soil and crop needs:

1. **Compost-Enriched Biochar:** Incorporates organic matter and diverse microbial populations. This type of enrichment enhances nutrient cycling and soil organic carbon.
2. **Fertilizer-Enriched Biochar:** Involves mixing or soaking biochar in solutions of inorganic fertilizers (e.g., urea, ammonium nitrate, superphosphate). These biochars provide immediate and sustained nutrient availability.
3. **Microbial-Enriched Biochar:** Inoculated with beneficial microbes such as Rhizobium, Azotobacter, or Trichoderma. These organisms aid in nitrogen fixation, disease resistance and plant growth promotion.
4. **Organic Waste-Enriched Biochar:** Agricultural or food waste can be co-composted with biochar, leading to a nutrient-rich amendment.

Effects on Soil Health and Fertility

Application of enriched biochar significantly improves soil properties:

- **Physical Properties:** Enhances soil structure, increases porosity and water-holding capacity and reduces bulk density.
- **Chemical Properties:** Improves nutrient availability, increases soil pH (especially in

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acidic soils) and enhances buffering capacity.

- **Biological Properties:** Stimulates microbial activity, increases enzymatic actions and promotes beneficial soil flora.

Environmental Benefits of Enriched Biochar

1. **Carbon Sequestration:** Biochar is highly stable and can store carbon in the soil for hundreds of years, helping mitigate climate change.
2. **Reduced Nutrient Leaching:** Acts as a filter for nutrients, especially nitrogen and phosphorus, preventing them from entering water bodies.
3. **Lower Greenhouse Gas Emissions:** Suppresses emissions of nitrous oxide, a potent greenhouse gas emitted from fertilized soils.
4. **Waste Valorization:** Utilizes agricultural residues and organic waste, reducing landfill usage and methane emissions.

Challenges and Limitations

Despite its potential, several challenges limit the large-scale adoption of enriched biochar:

- **Cost and Labor:** Production and enrichment require infrastructure, labor and materials that may not be readily available to smallholder farmers.
- **Lack of Standardization:** There is limited guidance on optimal enrichment methods, application rates, and quality standards.
- **Variability in Feedstock and Pyrolysis Conditions:** Inconsistent raw materials can affect biochar quality and efficacy.
- **Knowledge and Awareness Gaps:** Farmers and extension agents often lack information on enriched biochar benefits and use.

Future Prospects and Research Needs

To promote widespread adoption, research and policy support are essential. Key areas for future work include:

1. **Long-Term Field Trials:** Examine the sustained impact of enriched biochar across various soil types and climates.
2. **Development of Low-Cost Production Technologies:** Reduce barriers for smallholder adoption.
3. **Customized Enrichment Formulations:** Tailor biochar to specific crops and soil needs.
4. **Policy Incentives and Subsidies:** Support biochar adoption through subsidies, training, and integration into climate-smart agriculture policies.
5. **Public-Private Partnerships:** Encourage collaboration to commercialize biochar technologies and expand market access.

Conclusion

Enriched biochar represents a transformative technology in the quest for sustainable and efficient agricultural practices. By enhancing nutrient-use efficiency, improving soil health, and delivering environmental co-benefits, enriched biochar offers a win-win solution for farmers and ecosystems. However, to unlock its full potential, it is imperative to address technical, economic, and awareness-related barriers through coordinated research, education and policy initiatives. As agriculture transitions towards sustainability and climate resilience, enriched biochar stands out as a valuable and strategic input.

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APPLICATION OF UAV PESTICIDE SPRAYING IN PADDY FIELDS

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Introduction

In the rapidly evolving agricultural sector, technological advancements are reshaping traditional farming practices. Among these innovations, Unmanned Aerial Vehicles (UAVs), commonly known as drones, are revolutionizing pesticide spraying in paddy fields. These cutting-edge machines provide farmers with a more precise, cost-effective, and environmentally friendly alternative to conventional pesticide application methods.

I. The Growing Need for UAVs in Paddy Cultivation

Rice is one of the most widely consumed staple foods, feeding over 3.5 billion people worldwide. With global rice demand expected to rise by 25% by 2050, efficient and sustainable farming methods are critical to meeting this need. Paddy fields are particularly vulnerable to pests, with major rice-growing regions losing up to 37% of their total yield due to pest infestations, weeds, and diseases.

Traditionally, farmers have relied on manual spraying or tractor-mounted sprayers, both of which are labor-intensive, time-consuming, and prone to uneven chemical distribution. UAV pesticide spraying has emerged as a game-changer, addressing these challenges with precision, speed, and reduced environmental impact. According to a report by the International Rice Research Institute (IRRI), farms utilizing UAVs for pesticide application have reported up to a 30% increase in efficiency and a 50% reduction in pesticide usage.

II. How UAV Pesticide Spraying Works

Modern agricultural drones are equipped with GPS navigation, AI-driven sensors, and high-capacity sprayers that ensure optimal pesticide application. These UAVs operate autonomously or via remote control, covering vast areas in a fraction of the time required by traditional methods.

1. **Pre-Flight Planning**: Farmers or drone operators map out the paddy field using GPS technology to create an optimized spraying route.
2. **Automated Spraying**: UAVs fly at a precise altitude, dispersing pesticides evenly across the field while adjusting spray intensity based on crop health data.
3. **Real-Time Monitoring**: Many advanced drones provide live feedback, allowing farmers to make real-time adjustments and ensure efficient pesticide application.
4. **Data Collection & Analysis**: Some UAVs are capable of capturing high-resolution images and data that help farmers monitor pest outbreaks and crop health over time.

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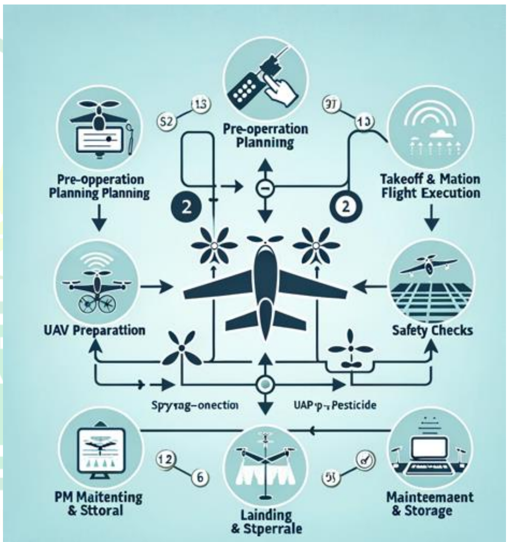
UAV applied Pesticide Spraying in Paddy field

III. UAV Pesticide Spraying Operation

The operational efficiency of UAV pesticide spraying has been well-documented in several studies. Below are key operational statistics:

1. **Coverage Area**: A single UAV can cover 10-50 hectares per day, compared to 1-2 hectares per day using manual labor, tractor operated sprayers and automatic sprayers.
2. **Spray Rate**: Most agricultural drones can spray at a rate of 4-6 liters per hectare, reducing excess pesticide usage.
3. **Flight Speed**: UAVs typically operate at 3-6 meters per second, ensuring rapid coverage while maintaining precision.
4. **Spray Droplet Size**: Drones deliver fine mist spray droplets of 45-180 microns, allowing better absorption and reducing pesticide drift.
5. **Battery Life & Refill Time**: Modern UAVs have a flight time of 25-35 minutes per charge based on the pay loads if the pay load increases then the discharge of battery has been take place, with quick battery swaps allowing continuous operation. Refilling of pesticide tanks takes approximately 4-6 minutes, ensuring minimal downtime this means reducing the time consumption when compare with the other spraying methods.

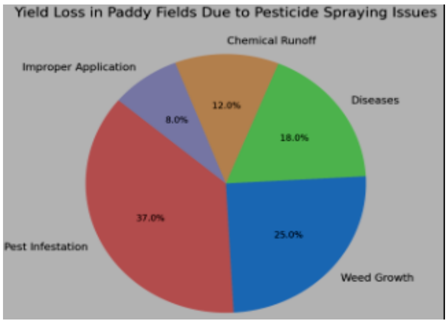
According to a study conducted by the Institute of Agricultural Engineering, UAV pesticide spraying has shown positive impact to improve operational efficiency by 60-80% when compared to traditional existing methods. In China, where drone adoption in agriculture has surged, UAVs have been reported to reduce spraying time by up to 90% compared to manual labor.



Flow chart for the operation of drone for pesticide spraying

IV. Yield Loss Due to Pesticide Spraying Issues

Yield loss in paddy fields occurs due to various pesticide spraying inefficiencies, including pest infestation, weed growth, diseases, chemical runoff, and improper application. The pie chart below illustrates the proportion of yield loss attributed to these factors:



1. Improved Efficiency and Coverage

UAVs can cover large rice fields quickly and efficiently, reducing the time required for pesticide application. In China, where drone adoption in agriculture has surged, UAVs have been reported to reduce spraying time by up to 90% compared to manual labor.

2. Precision and Reduced Chemical Waste

With AI-powered technology, drones apply pesticides only where needed, preventing excessive chemical use. A study conducted by the Institute of Agricultural Engineering found that UAV pesticide spraying reduces chemical waste by 30-50%, minimizing harmful environmental effects.

3. Cost-Effective Solution for Farmers

Compared to traditional methods, UAV pesticide spraying lowers operational costs by minimizing pesticide consumption and reducing the need for manual labor. A research paper published in the Journal of Precision Agriculture indicated that farmers using UAVs for spraying saved an average of 20-30% in pesticide costs annually.

4. Enhanced Safety and Worker Health

Manual pesticide spraying exposes farmers to harmful chemicals, posing significant health risks. The World Health Organization (WHO) estimates that approximately 3 million cases of pesticide poisoning occur annually, with severe cases leading to chronic illnesses and fatalities. UAVs eliminate direct human contact with pesticides, ensuring a safer working environment.

5. Environmental Sustainability

By reducing chemical runoff and ensuring precise pesticide application, UAVs contribute to a more sustainable farming ecosystem. The FAO reports that improper pesticide application results in 20-30% of chemicals contaminating nearby water bodies, affecting aquatic life and soil quality. Drones help mitigate this by applying chemicals accurately, reducing environmental degradation.

V. Challenges and Future Prospects

While UAV pesticide spraying offers numerous advantages, some challenges remain:

1. **High Initial Investment**: The cost of agricultural drones ranges from Rs.100,000 to 10,00,000 making it a significant investment for small-scale farmers.
2. **Regulatory Restrictions**: Many countries still have stringent regulations governing UAV use in agriculture, delaying widespread adoption.
3. **Technical Training**: Effective drone operation requires technical knowledge, which may necessitate additional training for farmers.

However, as drone technology continues to advance and regulatory frameworks adapt, these barriers are expected to diminish. Countries such as China, Japan, and the U.S. are already offering subsidies and training programs to encourage drone adoption in agriculture.

Future developments in UAV technology may include enhanced AI capabilities, real-time crop health analysis, and automated pesticide refilling systems. Additionally, increased government support and investment in smart agriculture could accelerate the widespread use of UAVs in paddy farming.

Conclusion

UAV pesticide spraying is transforming paddy field management by offering farmers a more efficient, precise, and eco-friendly solution. With global food demand rising, embracing innovative technologies like UAVs is essential for sustainable agriculture. Farmers who integrate drone technology into their operations benefit from increased yields, reduced costs, and improved environmental sustainability.

As more farmers embrace UAV pesticide spraying, rice cultivation is becoming more productive and resilient. With ongoing technological advancements and supportive policies, UAVs are set to become an integral part of modern rice farming, ensuring food security while preserving the environment for future generations.

References

1. Panjaitan, S.D., Dewi, Y.S.K., Hendri, M.I., Wicaksono, R.A. and Priyatman, H., 2022. A drone technology implementation approach to conventional paddy fields application. Ieee Access, 10, pp.120650-120658.
2. Wongsuk, S., Qi, P., Wang, C., Zeng, A., Sun, F., Yu, F., Zhao, X. and Xiongkui, H., 2024. Spray performance and control efficacy against pests in paddy rice by UAV-based pesticide application: effects of atomization, UAV configuration and flight velocity. Pest Management Science, 80(4), pp.2072-2084.
3. Wang, G., Li, X., Andaloro, J., Chen, P., Song, C., Shan, C. and Lan, Y., 2020. Deposition and biological efficacy of UAV-based low-volume application in rice fields. International Journal of Precision Agricultural Aviation, 3(2).
4. Ragiman, R. and Talluri, K.B., 2024. Unmanned aerial vehicle (UAV)-assisted pesticide application for pest and disease prevention and control in rice. International Journal of Agricultural and Biological Engineering, 17(5), pp.88-95.
5. Eun, H.R., Kim, S.H., Lee, Y.H., Kim, S.M., Lee, Y.J., Jung, H.Y., Min, Y.G., Noh, H.H. and Shin, Y., 2024. Comparison of off-target pesticide drift in paddy fields from unmanned aerial vehicle spraying using cellulose deposition sampler. Ecotoxicology and Environmental Safety, 285, p.117075.
6. Zhou, Q., Xue, X., Qin, W., Chen, C. and Cai, C., 2020. Analysis of pesticide use efficiency of a UAV sprayer at different growth stages of rice. International Journal of Precision Agricultural Aviation, 3(1).
7. Castaldi, F., Pelosi, F., Pascucci, S. and Casa, R., 2017. Assessing the potential of images from unmanned aerial vehicles (UAV) to support herbicide patch spraying in maize. Precision agriculture, 18, pp.76-94.

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BLACK ROT OF CRUCIFERS: DEVASTATING YIELD LOSSES

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Xanthomonas campestris pv. campestris is the causative agent of black rot, one of the most destructive diseases that cruciferous crops face worldwide. Around the world, crucifers—such as spinach, broccoli, cauliflower, and cabbage—are vital sources of nutrition and income. However, under ideal circumstances, black rot can cause production losses of up to 70%, which has a substantial effect on food safety and farmer livelihoods. The use of chemical treatments, crop rotation, and pathogen-free seeds are all major components of current control efforts, although they are frequently inadequate and not long-term viable. In addition, by changing pathogen-host interactions and creating favourable conditions for infection, climate change increases the severity of disease. The epidemiology, pathophysiology, and management techniques of black rot are critically reviewed in this article, with a focus on the necessity of integrated management strategies that include chemical, biological, and cultural controls as well as some novel approaches.

Keywords: Black rot, Cabbage, Phytopathological aspects, Management

INTRODUCTION

With an impressive yield of 9.59 million tonnes and a sizable cultivated area of 0.4 million hectares, India is the world's second-largest producer of cabbage (*Brassica oleracea L. var. capitata*). Cruciferous crops are susceptible to black rot, which is a major source with major agricultural losses worldwide and is brought on by the gram-negative bacterium *Xanthomonas campestris pv. campestris* (Sharma *et al.* 2017). The disease, which starts in seeds and soil, can enter plants through their roots, injuries, hydathodes, and stomata on their leaves. Together with xanthan, bacterial cells block xylem vessels, preventing water from moving through them and resulting in characteristic v-shaped lesions that start at the leaf margins. Darkened veins, tissue chlorosis, discolouration, leaf dislocation, and eventually plant death are all signs of these disorders. Early defoliation has been shown to significantly reduce yield, and the quality of cabbage and cauliflower heads has decreased. According to Gupta *et al.* (2013), losses in cauliflower and cabbage might range from 50% to 70%.

MAJOR SYMPTOMS OF BLACK ROT

- **IN SEEDLINGS**
  Black rot is especially dangerous to young seedlings. When cotyledons (seed leaves) fall off, the initial infections may appear to go away, but the bacteria are still present in plants at low concentrations. When the bacteria travels via the veins of leaves, infections become systemic.
- **MATURE PLANTS**
  Initially, there are obvious yellow V-shaped lesions along the leaf margins, each with the bottom facing inward. When lesions become necrotic, or dead, they become brown(Figure 1) and enlarge until whole leaves turn yellow, wilting and fall off the plant.

Affected leaf veins change colour from green to a dark brown to black.(Figure 2)

MANAGEMENT PRACTICES AGAINST BLACK ROT

CULTURAL PRACTICES

- Pathogens can be killed from seeds by treating them with Aureomycin 1000 ppm for 30 minutes.
- Adding 0.5% formaldehyde to nursery soil can aid with disease management.

Figure 1: Initial stages of the disease is observed at the top of the leaves

Figure 2: Major parts of leaves are attacked by Black Rot

- Black rot is frequently managed with copper fungicides. However, some claim that because copper fungicides resulted in black blotches on leaves, they were banned.
- The illness can be prevented by subjecting seeds to a bath with hot water at 50°C for 30 minutes. It may, however, reduce the rate of germination.

MECHANICAL PRACTICES

- Plant where the ground drains properly. Plants should be arranged in rows for optimal air drainage.
- When administered at the correct concentrations, general-purpose disinfectants can be efficient against *Xanthomonas sp*.
- Eliminating Brassica family weeds.
- Using of some resistant varieties like Bobcat, Defender, Guardian etc.

CHEMICAL CONTROL

- S-methyl acibenzolar Actigard and other products include this active component, which works well as a prophylactic strategy.
- Products made of copper These products can be used in the field or greenhouse after being tank mixed with mancozeb. The whole plant, particularly the underside of the leaves, can be sprayed with copper hydroxide products such as Kocide 101, Champion, or Coback.
- The antibiotic streptomycin In the greenhouse, this could reduce illness in transplants.

CONCLUSION

The worldwide production of cabbage is severely hampered by black rot. This terrible illness affects quality and yield, making sustainable cabbage farming difficult. An integrated strategy that incorporates biological, chemical, and cultural tactics is necessary for effective control. Crop rotation, the adoption of disease-free seeds, and good sanitation practices have all been demonstrated to reduce pathogen inoculum in their chosen field. Furthermore, using resistant cultivars is still one of the most environmentally benign and sustainable alternatives, even though continued breeding efforts are necessary due to the disease races' constant evolution.

In order to improve prevention of diseases and assure sustainable cabbage production, future research should focus on integrated disease management (IDM) systems that combine modern innovations with conventional techniques. Stakeholders may reduce the financial losses brought on by black rot and guarantee the continued viability of cabbage as a vital crop in world agriculture by utilising multidisciplinary approaches.

REFERENCE

1. Gupta, M., Vikram, A., & Bharat, N. (2013). Black rot-A devastating disease of crucifers: a review. *Agricultural Reviews, 34(4)*, 269-278.
2. Sharma, B. B., Kalia, P., Singh, D., & Sharma, T. R. (2017). Introgression of black rot resistance from Brassica carinata to cauliflower (*Brassica oleracea botrytis group*) through embryo rescue. *Frontiers in plant science, 8,* 1255.

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SOIL TO SOFTWARE: INTEGRATING AI IN MODERN AGRICULTURE

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Introduction: The Digital Transformation of Agriculture

Agriculture, a cornerstone of human civilization, is undergoing a significant transformation with the integration of Artificial Intelligence (AI). This shift is driven by the need to enhance productivity, ensure sustainability, and meet the growing global food demand. AI technologies are enabling farmers to make data-driven decisions, optimize resource utilization, and improve crop yields. From soil analysis to predictive analytics, AI is revolutionizing every facet of farming.

1. AI-Driven Soil Analysis and Health Monitoring

Soil health is fundamental to agricultural productivity. AI-powered tools, such as those developed by Farmonaut and Krishitantra, utilize sensors, drones, and satellite imagery to monitor soil properties, including nutrient levels, pH, and moisture content. These technologies provide farmers with precise soil maps, enabling targeted interventions and efficient resource allocation. By analyzing soil data, AI systems can recommend optimal fertilization strategies, enhancing soil fertility and crop yields.

The Importance of Soil Health in Modern Agriculture

Soil health is a cornerstone of agricultural productivity and sustainability. Healthy soils support plant growth, enhance water retention, and contribute to carbon sequestration. Traditional methods of assessing soil health, such as manual sampling and laboratory analysis, are often time-consuming, labor-intensive, and may not provide real-time insights. The integration of Artificial Intelligence (AI) into soil analysis offers a transformative approach, enabling real-time monitoring, predictive analytics, and data-driven decision-making.(digitalsinnovation.com)

AI-Powered Tools and Technologies for Soil Analysis

Several AI-driven tools have emerged to revolutionize soil health monitoring:

- **FarmLab**: Utilizes AI and satellite imagery to measure and manage soil carbon levels, aiding in sustainable farming practices and carbon credit verification. (theaustralian.com.au)
- **CropX**: Offers an AI-driven soil sensor platform that provides real-time data on soil moisture and nutrient levels, optimizing irrigation and fertilization strategies. (manoftech.com)
- **OneSoil**: Leverages satellite imagery and machine learning to provide farmers with insights into crop performance, soil conditions, and weather patterns, facilitating precision agriculture. (flypix.ai)
- **Dimitra**: Combines machine learning, IoT, and blockchain to offer a connected soil monitoring platform, providing in-depth soil analysis and ensuring data security. (startus-insights.com)
- **Farmonaut**: Employs AI to analyze satellite imagery for crop and soil monitoring, offering features like crop health analysis, irrigation management, and soil health assessment. (farmonaut.com)

Benefits of AI-Driven Soil Health Monitoring

Integrating AI into soil health monitoring offers numerous advantages:

- **Real-Time Data Acquisition**: AI tools provide immediate insights into soil conditions, enabling timely interventions.
- **Precision Agriculture**: By analyzing data at a granular level, AI facilitates targeted application of inputs, reducing waste and enhancing efficiency.
- **Predictive Analytics**: AI models can forecast soil health trends, allowing for proactive management strategies.
- **Resource Optimization**: Efficient use of water, fertilizers, and other inputs leads to cost savings and environmental benefits.
- **Scalability**: AI solutions can be scaled to monitor large agricultural areas, making them suitable for both smallholder and commercial farms.

Case Studies: Real-World Applications

The practical implementation of AI in soil health monitoring has yielded positive outcomes:

- **GreenField AgriTech**: Developed an AI-powered soil assessment tool that analyzes soil data in real-time, leading to a 20% increase in crop yields and reduced fertilizer costs. (thefarminginsider.com)
- **EcoSoil Solutions**: Introduced an AI diagnostic platform that helps identify soil health issues early, resulting in a significant reduction in crop loss. (thefarminginsider.com)
- **Kenyan Farmers**: Adoption of AI tools like Virtual Agronomist and PlantVillage has enabled small-scale farmers to improve productivity and reduce costs. (theguardian.com)

Challenges and Considerations

While AI offers transformative potential, certain challenges must be addressed:

- **Data Quality and Availability**: Accurate AI predictions depend on high-quality, comprehensive data, which may be lacking in some regions.
- **Infrastructure Requirements**: Reliable internet connectivity and access to modern devices are essential for AI tool deployment.
- **Cost and Accessibility**: The initial investment for AI technologies may be prohibitive for smallholder farmers without financial support.
- **Training and Support**: Farmers need adequate training to effectively utilize AI tools and interpret data insights.

AI-driven soil analysis represents a significant advancement in agricultural practices, offering real-time insights, predictive capabilities, and resource optimization. As technology continues to evolve, the integration of AI into soil health monitoring will become increasingly accessible and essential for sustainable agriculture. By addressing current challenges and promoting widespread adoption, AI has the potential to revolutionize soil management and contribute to global food security.

2. Precision Agriculture: Optimizing Inputs and Maximizing Yields

Precision agriculture leverages AI to apply inputs like water, fertilizers, and pesticides with pinpoint accuracy. AI algorithms analyze data from various sources to determine the exact needs of different field zones, reducing waste and environmental impact. For instance, AI-driven irrigation systems assess soil moisture and weather forecasts to schedule watering efficiently, conserving water and ensuring optimal plant growth.

The Evolution of Farming Practices

Agriculture has undergone significant transformations over the centuries, evolving from traditional methods to more sophisticated, technology-driven practices. One of the most impactful advancements in recent times is precision agriculture, which leverages technologies like Artificial Intelligence (AI), the Internet of Things (IoT), and data analytics to optimize farming operations. By focusing on the precise application of inputs—such as water, fertilizers, and pesticides—precision agriculture aims to enhance crop yields, reduce waste, and promote sustainable farming practices.

Core Components of Precision Agriculture

1. Variable Rate Technology (VRT):

VRT enables the application of inputs at varying rates across a field, tailored to the specific needs of different zones. This approach contrasts with uniform application methods, allowing for more efficient use of resources. For instance, areas with nutrient-rich soil may require less fertilizer, while zones with deficiencies receive more targeted treatments. VRT can be implemented through:tomorrowdesk.com+3farmonaut.com+3climafix.in+3en.wikipedia.org

- **Map-Based VRT:** Utilizes pre-generated prescription maps based on soil sampling and field data to guide input application.farmonaut.com
- **Sensor-Based VRT:** Employs real-time sensors to assess field conditions and adjust input rates on-the-fly.

By adopting VRT, farmers can enhance crop performance, reduce input costs, and minimize environmental impact.farmonaut.com

2. AI-Powered Crop Monitoring:

AI technologies, combined with drones and satellite imagery, facilitate detailed monitoring of crop health. These systems can detect early signs of stress, disease, or pest infestations, enabling prompt interventions. For example, AI algorithms analyze multispectral images to identify areas of concern, allowing farmers to apply treatments precisely where needed, thus conserving resources and protecting yields.hogonext.com

3. Precision Irrigation Systems:

Water management is critical in agriculture, especially in regions facing water scarcity. Precision irrigation systems use AI and IoT sensors to monitor soil moisture levels, weather forecasts, and crop water requirements. These systems can automatically adjust irrigation schedules, ensuring crops receive the optimal amount of water, reducing waste, and promoting healthy growth. Theclimafix.in+1tomorrowdesk.com+1

Benefits of Precision Agriculture

1. Enhanced Resource Efficiency:

By applying inputs precisely where and when needed, precision agriculture minimizes waste and ensures optimal resource utilization. This efficiency not only reduces costs but also lessens the environmental footprint of farming activities.

2. Increased Crop Yields:

Tailoring inputs to the specific needs of crops leads to healthier plants and higher yields. For instance, farmers in Kenya using AI tools like Virtual Agronomist have reported significant increases in productivity, with some tripling their coffee yields.theguardian.com

3. Sustainable Farming Practices:

Precision agriculture supports sustainability by reducing over-application of chemicals, conserving water, and promoting soil health. These practices contribute to long-term agricultural viability and environmental conservation.hogonext.com

Challenges and Considerations

1. High Initial Investment:

The adoption of precision agriculture technologies can involve substantial upfront costs for equipment, software, and training. This financial barrier may be challenging for small-scale farmers without adequate support or subsidies.

2. Data Management and Analysis:

The effectiveness of precision agriculture relies heavily on accurate data collection and analysis. Farmers must be equipped with the skills and tools to interpret data and make informed decisions, necessitating ongoing education and support.

3. Infrastructure and Connectivity:

Reliable internet connectivity and power supply are essential for the operation of many precision agriculture systems. In regions with limited infrastructure, these requirements can hinder the implementation of advanced technologies.theguardian.com+7farmonaut.com+7farmonaut.com+7

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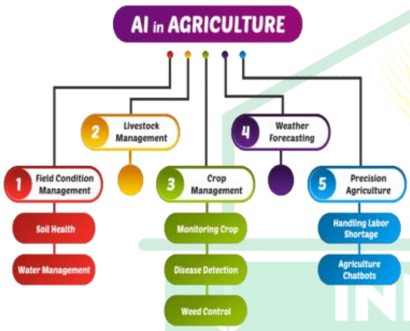
Future Outlook

The integration of AI and other advanced technologies in agriculture is poised to continue transforming the industry. Ongoing research and development aim to make precision agriculture more accessible, affordable, and user-friendly. Collaborations between governments, educational institutions, and private enterprises are crucial in driving innovation and supporting farmers in adopting these practices. As the global population grows and climate change presents new challenges, precision agriculture offers a promising path toward sustainable and efficient food production.

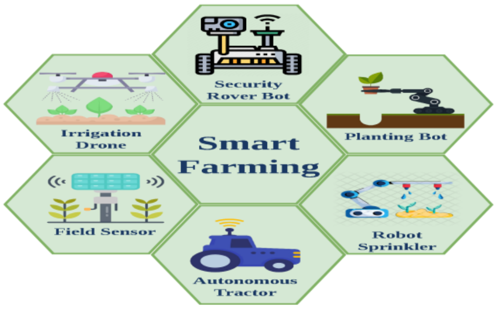


3. Smart Crop Monitoring and Disease Detection

AI enhances crop monitoring by employing computer vision and machine learning to detect plant diseases and pest infestations early. Tools like Plantix allow farmers to capture images of crops, which AI then analyzes to identify issues and suggest remedies. This proactive approach minimizes crop losses and reduces reliance on chemical treatments, promoting sustainable farming practices.

4. Predictive Analytics for Yield Forecasting

Predictive analytics powered by AI enables farmers to forecast crop yields by analyzing historical data, current field conditions, and weather patterns. These insights assist in planning harvests, managing supply chains, and making informed market decisions. By anticipating potential challenges, farmers can implement strategies to mitigate risks and optimize production.



5. Integrating AI into Farm Management Systems

Comprehensive farm management platforms, such as AgriStack, integrate AI to provide real-time insights into various farming operations. These systems consolidate data on soil health, crop status, weather forecasts, and market trends, offering actionable recommendations to farmers. By centralizing information, AI-driven platforms streamline decision-making processes, enhance operational efficiency, and support sustainable agricultural practices.

AI in Precision Agriculture: Process Flowchart

1. Data Collection

- **Sources**: Sensors (soil moisture, temperature), drones, satellites, and IoT devices.
- **Purpose**: Gather real-time data on soil conditions, weather patterns, crop health, and pest presence.

2. Data Processing and Analysis

- **AI Techniques**: Machine learning algorithms and computer vision.
- **Function**: Analyze collected data to identify patterns, predict outcomes, and detect anomalies.

3. Decision Support

- **Tools**: AI-driven software platforms.
- **Outcome**: Provide recommendations for irrigation scheduling, fertilization, pest control, and harvesting times.

4. Implementation

- **Methods**: Automated machinery, precision irrigation systems, and targeted pesticide application.
- **Goal**: Execute AI-informed decisions to optimize resource use and crop yields.

5. Monitoring and Feedback

- **Process**: Continuous monitoring of outcomes and system performance.
- **Adjustment**: Refine AI models and farming practices based on feedback to enhance accuracy and efficiency.

Conclusion: Embracing AI for a Sustainable Agricultural Future

The integration of AI into agriculture marks a pivotal shift towards more efficient, sustainable, and productive farming practices. By harnessing the power of AI, farmers can make informed decisions, optimize resource use and adapt to changing environmental conditions. As technology continues to evolve, embracing AI will be crucial in meeting the global food demand and ensuring the resilience of agricultural systems.

References:

- "Precision Agriculture: Optimizing Farming with AI & Sensors," TomorrowDesk.tomorrowdesk.com+1farmonaut.com+1
- "High tech, high yields? The Kenyan farmers deploying AI to increase productivity," The Guardian.theguardian.com
- "Farmers are using IoT to take the guesswork out of growing," Business Insider.businessinsider.com
- "Applications of Artificial Intelligence for Precision Agriculture," GeoPard Agriculture.geopard.tech

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MUSHROOM FORAGING

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Mushrooms are being used as food since time immemorial, have been considered as the delicacy from the nutrition point of view mushrooms are placed between meat and vegetables. Delicious, deadly, magical, intoxicating, mysterious; throughout history mushrooms have gained many varying reputations, considered both food and foe. Cultivation of edible mushrooms in India is of recent origin hence today it is easy for us to find safe, tasty mushrooms at the grocery store, but it wasn't always this way. Over the years mushroom hunters have foraged for delicious wild edible mushrooms.

Mushroom hunting, **mushroom picking**, **mushroom foraging**, and similar terms describe the activity of gathering mushrooms in the wild, typically for culinary use. Wild edible mushrooms have been collected and consumed by people since thousands of years. This practice is popular throughout most of Europe, Australia, Japan, Korea, parts of the Middle East, and the Indian subcontinent, as well as the temperate regions of Canada and the United States. Knowing where and when to search for mushrooms is an important identification skill that takes practice.

Foraging and eating of wild mushrooms has been a traditional practice in North East and North West India (Assam, Meghalaya, Nagaland, Manipur and Jammu Kasmir). In Japan, particular mushroom types are hunted, with particular importance given to delicacies such as the Matsutake mushroom which is the highest grade, can go up to $2000 per kilogram. In Slavic countries and Baltic countries, mushroom picking is a common family activity. The Russians Mushrooming is a commonplace tradition there, after a heavy rain during the mushroom season whole families often venture into the nearest forest, picking bucketfuls of mushrooms. In Southern Lithuania mushroom hunting is considered a "national sport". They even host a Mushroom Festival ("Grybų šventė") in Varėna including a mushroom hunting championship.

Points to be Observed for Identification of Fleshy fungi

General Appearance: Size, whether growing solitary or in groups, texture, color, any change of color with age or on drying, presence or absence of veils in the young stage.

Cap: Size, shape, color, nature of surface (whether smooth, slimy, scaly or fibrillose), kind of margin, whether easily separated from stem.

Stem: Size, shape (whether equal in thickness throughout or thickened above or below), color, nature of surface, presence of rings or vulva, whether the flesh is continuous with that of the cap or distinct (cartilaginous).

Tubes: Length, color, shape of mouth, mode of attachment to stem.

Gills: Color when young and later, texture, thickness, whether crowded or distant (spaced),

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whether all of the same length or of different lengths and method of attachment to the stem.

Flesh: Thickness, color, any change of color or exudation of a milky or colored juice when cut, texture, smell, taste.

Spores: For identification purposes, the microscopic characters of spores like color and other anatomical details are necessary. The properly dried specimens are filled in air tight polythene or paper packets and labeled.

Factors that help to identify edible from non-edible or toxic species

The place of growth – woods, grasslands, marshy area, etc.

- The way of growth – single, in a tuft or troop, or a ring.
- Smell of mushrooms.
- Change of color of mushrooms when cutting them.
- Shape, size, texture, and color of mushroom caps and stems – bulbous, rooting, ring/skirt, etc.
- Presence of bruises, spikes, markings, pores or gills on or under the cap.
- Texture of flesh.
- Time of the year – whether it is the season of mushrooms.

However, this cannot be totally relied on. Characterization by mushroom mycelial form are challenging for the reason that neither morphological characteristics nor organic/inorganic components help us differentiating them.

Commonly misidentified/confused mushrooms

Many mushroom guidebooks call attention to similarities between species, especially significant if an edible species is similar to, or commonly confused with, one that is potentially harmful. Few examples:

False chanterelles (*Hygrophoropsis aurantiaca*), as the name suggests, can look like real chanterelles (*Cantharellus cibarius*). Real chanterelles do not have sharp gills, but rather blunt veins on the underside. False chanterelles are considered edible, but unpleasant tasting. The Jack O'Lantern mushroom is also often mistaken for a chanterelle, and **it is potently toxic**.

False morels (*Gyromitra spp.* and *Verpa spp.*) resemble true morels. False morels have caps attached at the top of the stalk, while true morels have a honeycombed cap and a single, continuous hollow chamber within. Immature *Chlorophyllum molybdites* can be confused with edible *Agaricus* and *Macrolepiota* mushrooms.

Over the years reckless mushroom hunters have thrown caution to the wind with sometimes fatal results, giving food-safe mushrooms a bad reputation. It's resulted in two very different categories of people—mycophiles (those who love mushrooms) and mycophobes (those who fear mushrooms).

Mushroom poisoning may be resulting from the ingestion of mushrooms that contain toxic substances. Its symptoms can vary from slight gastrointestinal discomfort to death in about 10 days. Mushroom toxins are secondary metabolites produced by the fungus. The most common reason for this misidentification is a close resemblance in terms of color and general morphology of the toxic mushrooms species with edible species. To prevent mushroom poisoning, mushroom gatherers familiarize themselves with the mushrooms they intend to collect, as well as with any similar-looking toxic species.

There are certain chemical tests available to identify mushrooms in the foraging aided with preliminary knowledge on mushroom morphology. The most useful tests are Melzer's reagent and potassium hydroxide.

Chemical tests in mushroom identification

Ammonia: Household ammonia can be used. A couple of drops are placed on the flesh. For example, *Boletus spadiceus* gives a fleeting blue to blue-green reaction.

Iron salts; Iron salts are used commonly in *Russula* and *Bolete* identification. It is best to dissolve the salts in water (typically a 10% solution) and then apply to the flesh, but it is

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sometimes possible to apply the dry salts directly to see a color change. For example, the white flesh of *Boletus chrysenteron* stains lemon-yellow or olive. Three results are expected with the iron salts tests: no change indicates a negative reaction; a color change to olive green or blackish green; or a color change to reddish-pink.

Meixner test for amatoxins: The Meixner test (also known as the Wieland test) uses concentrated hydrochloric acid and newspaper to test for the deadly amatoxins found in some species of *Amanita*, *Lepiota*, and *Galerina*. The test yields **false positives for some compounds, such as psilocin**.

Melzer's reagent: Melzer's reagent can be used to test whether spores are amyloid, nonamyloid, or dextrinoid. Spores that stain bluish-gray to bluish-black are amyloid spores that stain brown to reddish-brown are dextrinoid. This test is normally performed on white spored mushrooms. If the spores are not light colored, a change will not be readily apparent. It is easiest to see the color change under a microscope, but it is possible to see it with the naked eye with a good spore print.

Para dimethyl amino benzaldehyde: In the genus *Lyophyllum* the lamellae usually turn blue with the application of para-Dimethyl amino benzaldehyde (PDAB or pDAB).

Phenol: A 2–3% aqueous solution of phenol gives a color change in some species when applied to the cap or stem.

Potassium hydroxide: A 3–10% solution of potassium hydroxide (KOH) gives a color change in some species of mushrooms: A change to yellow is sometimes found in species of *Agaricus* and *Amanita*; magenta or olive reactions can help identify species of *Russula* and *Lactarius*; deep red or black reactions can help sort out many gilled mushrooms; black reactions among polypores are crucial separators; and various colors are produced with boletes. In *Agaricus*, some species such as *A. xanthodermus* turn yellow with KOH, many have no reaction, and *A. brutilescens* turns green.

Sulfo-vanillin: Made from sulfuric acid (HSO) and vanillin (vanilla). Used in *Russula* and *Panaeolus* identification.

Unfortunately foraging as a concept has been lost, with the advent of lack of expert mycologists to spot the mushrooms in turn mono cultivation and availability in supermarket shelves.

Nowadays, we have begun to eat, not from a geographic perspective, nor from ancestry but from what the market dictates. In the same way, we eat the mushrooms that the market dictates – button mushrooms while forgetting or not getting the various many beautiful, medicinal, and nutrient-rich mushrooms available in our lands.

Our tribes in India and forest communities are the last piece of information on empirical knowledge with the fungal kingdom and unique species.

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Popular Edible Mushrooms


Milky mushroom


Button mushroom


Shittake mushroom


Oyster mushroom


Boletus mushroom


Honey mushroom


Enoki mushroom


Reishi mushroom

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Nano-Enabled Seed Priming: Revolutionizing Seed Viability and Agricultural Productivity

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Nano-enabled seed priming is an innovative agricultural technique that integrates nanotechnology with traditional seed priming methods to enhance seed germination, vigour, and stress tolerance. Seed priming involves controlled hydration of seeds to initiate early metabolic processes without radicle protrusion, leading to faster and more uniform seedling emergence even under adverse environmental conditions. The biochemical mechanisms underlying seed priming include activation of enzymes, DNA repair, and metabolic adjustments that prepare the seed for rapid germination and robust seedling growth. Nanoparticles (1–100 nm in size) having unique properties such as high surface area and reactivity, can be used as priming agents to enable better seed germination and protection from microbial contamination. This enhances water uptake by stimulating aquaporin gene expression, activates stress-resistance genes, boosts antioxidant enzyme activity and improves seed storage viability. Overall, nano-enabled seed priming offers a promising, eco-friendly approach to improve crop productivity and resilience, addressing global food security challenges while minimizing environmental impact.

1. Introduction

Seeds being important for the germination and growth of plants i.e. the crucial stage in the plant's life cycle, ensures the food security. Traditional methods of enhancing the crop, such as the use of pesticides and fertilizers, pose a significant environmental challenge, including environmental pollution, leaching out and other detrimental effects. To fix the burning issues regarding seed damage and compromised yield, there is need to come up with sustainable technology in order to maintain seed health and seedling growth. Vital aspects of crop improvement by maintaining sustainability can be accomplished through modulating the metabolism of seed that would be achieved by seed priming technique (Devika et al., 2021). Historically, seeds were simply subjected to pre-sowing treatments to enhance their germination efficacy and ensure they were adequately prepared prior to planting. But, now a days, NMs are being used to boost seedling health. Different treatments and methods are used incorporating these NPs to make sure we get top-quality plants. An important strategy which is called "nano-priming," where dry seeds are soaked in these minute materials to help growth and water absorption. Interestingly, even after the seeds absorb these materials, they still have some left on their surface. Additionally, bactericides or fungicides can be used on seed coats to prevent infections. Priming agents are only external agents that have already absorbed on the seed coat. The seed coat, composed of sclerenchyma, which offers physicochemical protection against environmental risks, must be penetrated by NPs in order for them to interact with seeds (Mahra *et al.*, 2025). Since primed seeds are physiologically close to germination stage, they show an enhanced germination rate, early and uniform germination, improved growth attributes, faster emergence and better establishment of crop stand. It improves the mean performance of a seed lot by reducing the variation due to staggered emergence within a seed lot. This also allows the 'poor' seeds to catch up with the 'good' ones during the pre-sprouting germination events. Thus, it results in lesser emergence time, vigorous seedling growth, and uniform crop stand of direct-seeded vegetable crops. It alleviates the stress at the germination stage and ultimately results in the successful seedling establishment under an abiotic stress environment (Thakur *et al.*, 2022).

2. Seed Priming: concept and types

Seed priming is a promising strategy to provide a valuable solution to enhance the planting value of high-value crops. It is a pre-sowing seed treatment that allows controlled hydration of seeds to imbibe water and go through the first stage of germination but does not allow radical protrusion through the seed coat (Thakur *et al.*, 2022). Seed priming hastens the germination process and enhances the rate of seedling emergence even under extreme climatic conditions and in problem soils (Devika *et al.*, 2021). Seed priming methods can be categorised in two major groups: invasive and non-invasive (Figure 1), based on the property of technique to bring about changes in the seed coat and endosperm/cotyledon. Since the invasive techniques are primarily wet priming treatments, the gradual imbibition of water during priming results in softening of the seed coat and activation of metabolic processes within the seed. Non-invasive technique on the other hand, does not reqire any type of wet priming treatment; uses different types of radiations instead hydration (Thakur *et al.*, 2022). All these non-invasive methods depend upon robust and highly automated instruments that prime the seeds in a throughput manner. These methods are environment friendly as no waste is left after the priming treatment and therefore, can be recommended in the package of practices for organic farming. However, the unfavourable feature of these methods is that the installation is cost intensive and skilled personnel are required to operate the instruments. On the other hand, invasive methods do not allow bulk seed treatment and are not environment friendly as chemical waste is generated. Nevertheless, they are cost effective treatments (Thakur *et al.*, 2022).

3. The Role of Nanotechnology in Seed Priming

Nanotechnology introduces a new dimension to seed priming by utilizing nanoparticles—materials with dimensions in the nanometer range (1–100 nm). These particles possess unique properties, such as high surface area, enhanced reactivity and controlled release capabilities, making them ideal for agricultural applications (Mahra *et al.*, 2025). Despite being relatively new in the agricultural sector, nanomaterials (NMs) exhibit significant potential in addressing various challenges, particularly in mitigating abiotic stress (Ioannou *et al.*, 2020). In nano-enabled seed priming, nanoparticles are used to deliver nutrients, growth regulators or protective agents directly to seeds. This targeted approach ensures efficient uptake, minimizes wastage and enhances the seed's ability to withstand environmental stressors. This technique integrates nanotechnology with traditional seed priming methods, offering a sustainable approach to agriculture by promoting better seed performance and resilience under various environmental stresses.

4. Mechanisms of seed priming

Priming exposes seed to stimuli, in response to which a set of interlinked biochemical changes occurs such as activation of enzymes, synthesis of growth-promoting substances, metabolism of germination inhibitors and repair of cell damage. The process of seed priming is accomplished in three stages. Seed imbibition is the stage I, where the seed uptakes water rapidly as the water potential of the seed is low. Stage II is known as the activation phase. This stage is characterized by a series of metabolic and repairing events at the cellular level (Figure 2). The moisture content decreases and the major changes documented during this stage include synthesis of protein, formation of new mitochondria, activation of enzymes and antioxidant system and DNA repair. Seed

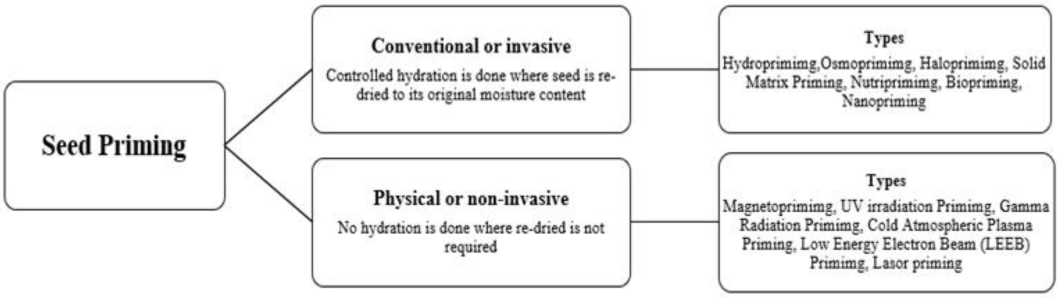

Figure 1 Different kinds of seed priming strategies to bestow the seed health

imbibition is stopped after this stage. Rehydration during seed priming induce changes at the cellular level such as cell division, synthesis of nucleic acids, protein, ATP production, increase in cell energy, ATP/ADP ratio for energy requirement, accumulation of essential lipids, production of antioxidants and activation of DNA repair mechanism. In the cell damage repair system, DNA repair is most crucial because, in case of defective repair, oxidative injury can lead to cell death during germination. Studies revealed that proteins, carbohydrates and lipid-mobilizing enzymes are activated during seed priming (Devika *et al.*, 2021). For example, α-amylase activity along with total soluble sugars increased in wheat when primed with benzyl aminopurine and sorghum water extract (Bajwa *et al.*, 2018). α-Amylase is known to hydrolyse the starch reserves (polysaccharides) into sugars (monosaccharides). Priming enhances protein synthesis by increasing the synthesis of rRNA and improving the integrity of ribosomes. Production of antioxidant enzymes such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD) and maintaining a balance between generation and destruction of ROS such as hydrogen peroxide, superoxide and hydroxyl radicals under stress conditions are important effects of seed priming. In stage III, the uptake of water is rapid, and protrusion of the radicle indicates that the germination process has entered into the growth and cell elongation phase (Devika *et al.*, 2021).

NM-mediated seed priming involves treating seeds with a solution containing nanoparticles (NPs) of metallic, biogenic, or polymeric in nature, which enhances seed germination, seedling vigour, and plant resilience. NPs enter the seed through either direct diffusion across the plasma membrane, depending on NP size, charge, and hydrophobicity or active transport via endocytosis (Shelar *et al.*, 2021). NPs create nano-pores in the seed coat, increasing its permeability. This facilitates rapid water uptake, which is further enhanced by the upregulation of aquaporin gene expression (aquaporins are water channel proteins) (Shelar *et al.*, 2021). The influx of water activates metabolic processes within the seed. NPs stimulate the activity of enzymes such as amylase, which breaks down starch reserves into soluble sugars, providing energy for the embryo (Donia *et al.*, 2023). NPs also promote the synthesis of gibberellic acid (GA), a phytohormone that triggers germination and seedling growth (Figure 2). Seed nano-priming increases the production of antioxidant enzymes like superoxide dismutase (SOD), which helps mitigate oxidative stress by neutralizing reactive oxygen species (ROS) (Figure 2) (Shelar *et al.*, 2021). Enhanced antioxidant activity protects the seed and seedling from environmental stresses, including drought, salinity, heavy

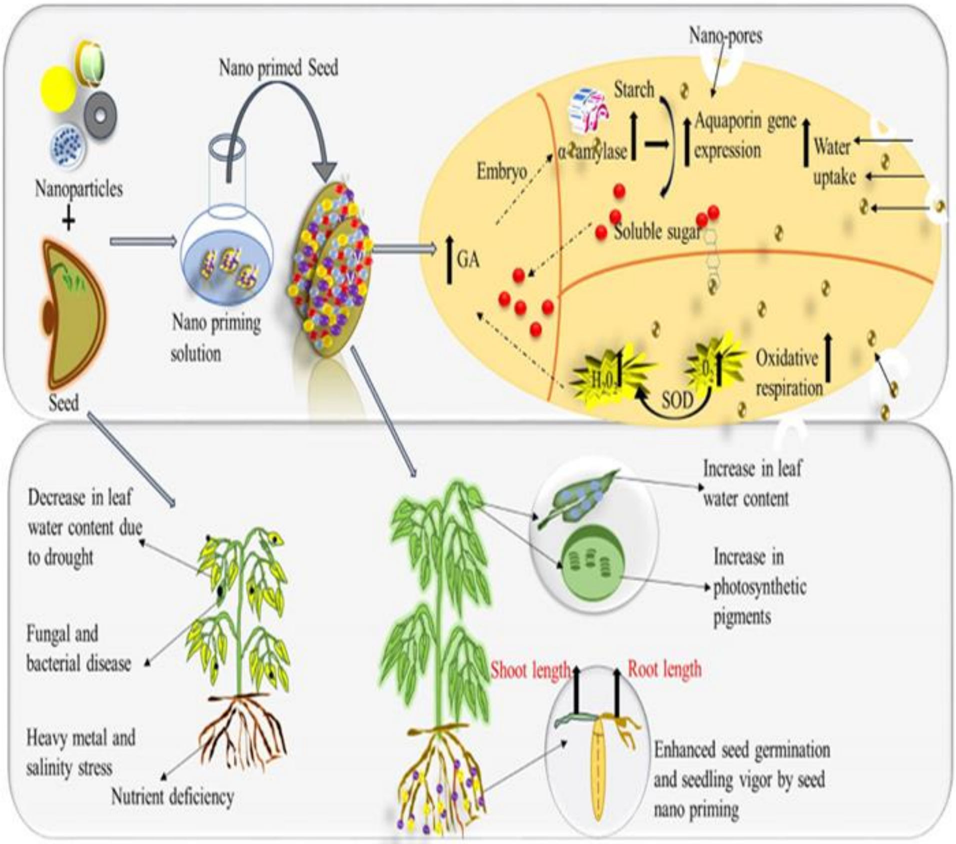

Figure 2 Schematic illustration showing mechanism of nano-enabled seed priming and their impact on plant growth enhancement

metals and pathogen attacks. Enhanced water uptake and metabolic activation lead to faster and more uniform germination. Increased soluble sugar availability fuels rapid seedling growth, resulting in longer shoots and roots. Plants from nano-primed seeds show increased leaf water content and higher levels of photosynthetic pigments, improving photosynthetic efficiency and resilience to stress. NM-mediated priming improves plant tolerance to abiotic stresses (drought, salinity, heavy metals) and biotic stresses (fungal and bacterial diseases) (Pereira *et al.*, 2021). Ultimately, this results in higher seedling vigour, better establishment and potentially increased crop yield.

5. Benefits of Nano-Enabled Seed Priming for Better Seed Viability

i. Nano-priming significantly improves seed germination rates and synchrony, enhanced water uptake, as nanoparticles stimulate the expression of aquaporin genes, facilitating faster & more efficient water absorption during imbibition, which is crucial for germination.

ii. Nano-priming activates stress-resistance genes and enhances the antioxidant enzyme activity in seeds and seedlings.

iii. Nano-priming provides protective effects during seed storage, reducing aging-related declines in viability and germination rates.

iv. Nanoparticles can act as carriers for nutrients and growth regulators, ensuring controlled release and better bioavailability, which further enhances seed germination and seedling growth.

v. Nano-priming can reduce the need for chemical pesticides and fertilizers, contributing to more sustainable agricultural practices. Some nanoparticles have inherent antimicrobial properties or can deliver antimicrobial agents, offering additional protection against seed-borne pathogens.

vi. Nano-priming can enhance starch and lipid metabolism, photosynthetic efficiency and the production of beneficial secondary metabolites in plants.

6. Conclusion

Nano-enabled seed priming represents a transformative leap in agricultural science, offering a sustainable and efficient solution to enhance seed viability and crop productivity. By harnessing the power of nanotechnology, this innovative approach has the potential to address global food security challenges while promoting environmentally responsible farming practices. As research and development continue to evolve, nano-enabled seed priming could become a cornerstone of modern agriculture, empowering farmers and ensuring a greener, more resilient future.

References:

1) Bajwa, A. A., Farooq, M., and Nawaz, A. (2018). Seed priming with sorghum extracts and benzyl aminopurine improves the tolerance against salt stress in wheat (*Triticum aestivum L.*). *Physiology and molecular biology of plants,* 24, 239–249.

2) Devika, O. S., Singh, S., Sarkar, D., Barnwal, P., Suman, J., and Rakshit, A. (2021). Seed priming: A potential supplement in integrated resource management under fragile intensive ecosystem. *Frontiers in Sustainable Food Systems,* 5, 654001.

3) Donia, D. T. and Carbone, M. (2023). Seed priming with zinc oxide nanoparticles to enhance crop tolerance to environmental stresses. *International Journal of Molecular Science,* 24(24), 17612.

4) Ioannou, A., Gohari, G., Papaphilippou, P., Panahi, Rad S., Akbari, A., Dadpour, M. R., Krasia-Christoforou, T., and Fotopoulos, V. (2020). Advanced nanomaterials in agriculture under a changing climate: The way to the future? *Environmental and Experimental Botany,* 176,104048.

5) Mahra, S., Tripathi, S., Tiwari, K., Sharma, S., Mathew, S., Kumar, V., and Sharma, S. (2025). Harnessing nanotechnology for sustainable agriculture: From seed priming to encapsulation. *Plant Nano Biology*, 100124.

6) Pereira, A. D. E. S., Oliveira, H. C., Fraceto, L. F. and Santaella, C. (2021). Nanotechnology Potential in Seed Priming for Sustainable Agriculture. *Nanomaterials (Basal)*, 11(2), 267.

7) Shelar, A., Singh, A. V., Maharjan, R. S., Laux, P., Luch, A., Gemmati, D., Tisato, V., Singh, S. P., Santilli, M. F., Shelar, A., Chaskar, M. and Patil, R. (2021). Sustainable agriculture through multidisciplinary seed nanopriming: Prospects of opportunities and challenges. *Cells,* 10(9), 2428.

8) Thakur, M., Tiwari, S., Kataria, S., and Anand, A. (2022). Recent advances in seed priming strategies for enhancing planting value of vegetable seeds. *Scientia Horticulturae,* 305,111355.

Flowers that flavour your plate and please your palate

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Edible flowers are gaining prominence in modern cuisine for their aesthetic appeal, unique flavors, and health benefits. Traditionally used in various cultures, particularly in Indian, European, and East Asian practices, flowers like rose, hibiscus, jasmine, calendula, and butterfly pea enhance dishes while offering medicinal value. These blooms are rich in antioxidants, vitamins, and essential oils that support digestion, boost immunity, and reduce stress. As interest in natural and functional foods grows, chefs and home cooks are increasingly exploring the culinary potential of flowers. However, caution is essential only properly identified, organically grown edible flowers should be consumed, as some species are toxic. For floriculturists, edible flower cultivation presents opportunities in organic gardening, value-added product development, and rural entrepreneurship. Products like gulkand, floral teas, and natural food colors have strong market potential. Thus, edible flowers represent a harmonious blend of tradition, nutrition, and sustainability, enriching both food culture and economic opportunity.

Keywords: Edible flowers, Culinary, Nutrition, Tradition, Health

Introduction

Flowers have captivated human senses for centuries with their beauty and fragrance. Beyond their decorative appeal, many flowers are edible and play an important role in culinary traditions worldwide. These edible blossoms add unique flavors, vibrant colors, and nutritional value to a variety of dishes. Their use ranges from fresh salads and teas to jams and desserts. With increasing interest in natural and healthful foods, edible flowers are gaining popularity among chefs and home cooks alike. They are rich sources of antioxidants, vitamins, and essential oils, which contribute to overall well-being. This article explores the historical significance, health benefits, safety considerations, and culinary uses of edible flowers, highlighting their growing role in modern cuisine.

Historical and Cultural Significance

Throughout history, edible flowers have held an important place in many cultures, often linked with medicine, rituals, and cuisine. Ancient Ayurvedic texts mention the use of flowers such as hibiscus and jasmine for healing purposes. In Indian culinary traditions, flowers like banana blossom and rose have been used in dishes and sweets for centuries. Rose petals are integral in making gulkand, a sweet preserve with cooling properties. Marigold flowers, besides their decorative use in temples and festivals, are also incorporated into meals for their flavor and health benefits. Globally, flowers like lavender in Europe and chrysanthemum in East Asia are traditionally used both for their taste and therapeutic effects. These cultural practices demonstrate a deep connection between humans and flowers, blending beauty with nutrition and healing. Today, these ancient customs inspire chefs and food lovers to rediscover edible flowers in new and creative ways.

While many flowers are edible and beneficial, it is crucial to remember that not all flowers are safe for consumption. Some flowers can be toxic or cause allergic reactions. Proper identification is essential before using any flower

Popular Edible Flowers and Their Uses

Common Name	Scientific Name	Culinary Uses	Medicinal Uses	Reference
Rose	*Rosa spp*	jams, syrups, gulkand, desserts, and flavoring	Rich in vitamin C; anti-inflammatory; immune booster	(Fernandes *et al.*, 2020)
Hibiscus	*Hibiscus rosa sinensis*	Herbal teas, chutneys, beverages	Lowers blood pressure; antioxidant; supports heart health	(Phillips, 2017)
Banana Flower	*Musa paradisiaca*	Curries, fritters, salads	High in fiber; iron source; aids digestion	(Rodrigues and Spence, 2023)
Pot Marigold	*Calendula officinalis*	Salads, teas, rice dishes	Anti-inflammatory; wound healing; antimicrobial	(Jadhav *et al.*, 2023)
Butterfly Pea	*Clitoria ternatea*	Teas, rice coloring, desserts	Neuroprotective; memory enhancer; reduces anxiety	(Santos and Reis, 2021)
Jasmine	*Jasminum sambac*	Flavored rice, desserts, teas	Natural antidepressant; relaxant	(Takahashi *et al.*, 2020)
Lavender	*Lavandula angustifolia*	Baking, herbal drinks, syrups	Calming, promotes relaxation	(Jadhav *et al.*, 2023)
Chamomile	*Matricaria chamomilla*	Herbal teas, flavoring	Calming; relieves stress and digestive discomfort	(Pensamiento *et al.*, 2024)

Caution: Not All Flowers Are Edible

in food. Flowers should be grown organically without pesticides or harvested from trusted sources to avoid contamination. Flowers purchased from florists or garden centers often contain chemicals not meant for ingestion. Common toxic flowers include oleander, daffodil, and foxglove, which can cause serious health issues if ingested. Additionally, some edible flowers may cause allergic reactions in sensitive individuals, so it is advisable to try a small amount first. Washing flowers thoroughly and consuming them fresh helps reduce the risk of foodborne illness. Awareness and caution ensure that the delightful use of edible flowers remains safe and enjoyable.

Edible Flower Gardening – A Floriculturist's View

Growing edible flowers at home not only adds charm to your garden but also enhances your kitchen. Ideal choices for edible flower gardening include rose, calendula, lavender, and butterfly pea. These can be grown in pots, borders, or intercropped with vegetables. For floriculture students, this opens avenues in:

- ❖ Organic gardening and kitchen garden projects.
- ❖ Development of value-added products like dried petals, herbal teas, and gulkand.
- ❖ Marketing through eco-shops and local fairs.
- ❖ Florist-café business models combining décor and food.

Conclusion

Edible flowers beautifully unite aesthetics, flavor, and wellness, offering a sensory and nutritional delight. Their resurgence in modern gastronomy reflects a growing appreciation for natural, sustainable, and traditional food sources. Beyond being mere garnishes, these blossoms carry cultural heritage and medicinal value, backed by scientific studies. They inspire innovative culinary creations while promoting healthy eating habits. In sustainable gardening,

Visual guide of edible flowers

edible flowers contribute to biodiversity and attract pollinators, making them eco-friendly choices. For rural communities, cultivating and marketing these flowers opens doors to value-added products and income generation. As floriculturists, embracing edible flowers enhances both our landscapes and livelihoods. Let us cherish and utilize these vibrant gifts that nourish the body, enrich traditions, and connect us to nature's wisdom.

Reference

Fernandes, L., Casal, S., Pereira, J. A., Saraiva, J. A., & Ramalhosa, E. (2020). An overview on the market of edible flowers. Food Reviews International, 36(3), 258-275. https://doi.org/10.1080/87559129.2019.1639727

Phillips, C. (2017). Treating Depression Naturally: How Flower Essences Can Help Rebalance Your Life. Floris Books. https://doi.org/10.1016/j.hermed.2019.100267

Rodrigues, H., & Spence, C. (2023). Looking to the future, by studying the history of edible flowers. International Journal of Gastronomy and Food Science, 34, 100805. https://doi.org/10.1016/j.ijgfs.2023.100805

Jadhav, H. B., Badwaik, L. S., Annapure, U., Casanova, F., & Alaskar, K. (2023). A review on the journey of edible flowers from farm to consumer's plate. Applied Food Research, 3(2), 100312. https://doi.org/10.1016/j.afres.2023.100312

Santos, I. C. D., & Reis, S. N. (2021). Edible flowers: traditional and current use. Ornamental Horticulture, 27, 438-445. https://doi.org/10.1590/2447-536X.v27i4.2392

Takahashi, J. A., Rezende, F. A. G. G., Moura, M. A. F., Dominguete, L. C. B., & Sande, D. (2020). Edible flowers: Bioactive profile and its potential to be used in food development. Food Research International, 129, 108868. https://doi.org/10.1016/j.foodres.2019.108868

Pensamiento-Niño, C. A., Castañeda-Ovando, A., Añorve-Morga, J., Hernández-Fuentes, A. D., Aguilar-Arteaga, K., & Ojeda-Ramírez, D. (2024). Edible flowers and their relationship with human health: Biological activities. Food Reviews International, 40(1), 620-639.

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EXTRACTION OF BROMELAIN FROM PINEAPPLE WASTE: A PROMISING THERAPEUTIC APPLICATION

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Bromelain is a proteolytic enzyme that is predominant in pineapple. It is present in the peel, leaf, stem and fruit. The demand for bromelain is increasing as it is an important nutraceutical in the clinical and therapeutic industry. Even though new extraction techniques have been developed to enhance bromelain extraction and purification and generate larger quantities without sacrificing enzymatic activity, these procedures are still costly and difficult. This article will outline the current state of the art for the primary conventional and non-conventional bromelain extraction, purification and their therapeutic application.

Keywords: Bromelain, nutraceutical, conventional, non-conventional methods and pharmacokinetic

Introduction

The pineapple, *Ananas comosus* L. Merryl, is a well-known source of the proteolytic enzyme bromelain, belongs to the family Bromeliaceae. It is found in smaller amounts than in stems and fruits, it can also be found in pineapple wastes including cores, peels, and leaves. It has been discovered that pineapple waste has potential applications as raw materials for value-added products. Pineapple waste has been utilized as a medium in culture broth, as well as for the creation of alcoholic beverage vinegar and frozen pineapple juice concentrate and the production of beneficial chemicals from pineapple trash. Bromelain is commercially used in the food industry, cosmetics, and nutritional supplements. The textile, brewing, baking, protein production, skin softening, hair removal, and detergent formulation sectors all use bromelain. Commercial bromelain can cost as high as 1,99,969 lakh rupees because of its wide range of uses.

Properties of Bromelain

Properties	Value
Peptide chain length(α+β Protein)	211 or 212 amino acids
Molecular Weight	22.8 kDa
Ideal pH of Stem Bromelain	6-7
Ideal Temperature of Stem Bromelain	37 to 70 °C
Storage Temperature	−20 °C

Conventional Methods of Bromelain Extraction

Pineapple aste like core, crown, peels and stems were cut into pieces and blended with water and the extract is taken. The extract is then homogenized to disrupt the cells of the waste and then it is centrifuged to remove the crude material without disturbing the nature of proteases. In comparison to fruit bromelain, stem bromelain has a higher enzymatic concentration. Then, the process is followed by ultrafiltration which is the best standard for concentration of protein. It has been demonstrated that membrane filtration, when combined with other processes, enhances the purification of bromelain. The last step is lyophilization, which is freeze drying, that

removes the water molecules. This happens when the proteins go from a soluble form called "molecular state" to a so-called particle state where they are not soluble in water. Stabilizers, like cryoprotectants, are therefore necessary to keep proteins stable throughout the lyophilization process. This conventional approach of bromelain extraction is currently used worldwide (Colletti *et.al*, 2021).

Non-conventional Methods of Bromelin Extraction

1. Aqueous Two-phase System

Aqueous two-phase systems, which use a reusable polymer and a salt or two reusable polymers, are an inexpensive, fast, scalable, ecologically benign method for the extraction and purification of several chemicals. This method often removes unwanted impurities like colors and polysaccharides while separating proteins and preventing denaturation. However, the enzymes in the extract can only withstand a limited number of organic solvents due to the nature of bromelain.

2. Chromatographic Techniques

One of the most often used chromatographic techniques for extracting bromelain is ion exchange chromatography, is an inexpensive, highly specific, scalable, and dependable method. Ananain has been separated using cation exchange chromatography in conjunction with affinity chromatography. Acetone precipitation combined with the two chromatographic methods has produced superior purification (85% of the original active proteases).

3. Reversible Micellar System

Reversed micellar extraction (RME), a simple to scale-up method that is feasible, moderately inexpensive, and energy-efficient. The raw bromelain extract contains proteins and enzymes that can be selectively separated using this procedure. Reversed micelles are aggregates of surfactant molecules that consist of inner core of water molecules. Using this method, a recovery of 85% (four-fold purification) of bromelain has been demonstrated (Chiarelli *et.al*, 2024).

4. Precipitation Methods

The process of precipitation involves the addition of various precipitating agents, such as salts, non-ionic polymers, and organic solvents such as ethanol, propanol, methanol, and ketones. 98% of the original enzymatic activity was obtained when ethanol (30–70%) was used for the extraction. Ammonium sulfate is also used for the extraction.

Clinical Application of Bromelain

- Dental application-tooth whitening.
- Heals the skin wounds and burns.
- Reduces the uric acid level.
- The reduction of Osteoarthritis and Rheumatic arthritis.
- Decrease the facial swelling in the early and later stage after surgery.
- Treat Acute Sinusitis, Rhinitis, Rhino sinusitis

Bromelain is considered as a safe nutraceutical (Rathnavelu *et.al*, 2016).

Conclusion

An intriguing nutraceutical called bromelain extract may be utilized as an adjuvant for a number of illnesses, such as inflammatory diseases, skin issues, sports injuries, sinusitis, and cardiovascular illnesses. However, the primary barriers to the application of these extracts are the low level of clinical research and the high expense of bromelain extraction and purification. Ultimately, in order to maximize extract yield and activity and perhaps produce a product that is commercially viable, additional research on the same matrices comparing traditional and non-conventional methods, or their combination, is required.

Reference

- Colletti, A.; Li, S.; Marengo, M.; Adinolfi, S.; Cravotto, G. Recent Advances and Insights into Bromelain Processing, Pharmacokinetics and Therapeutic Uses. Appl. Sci. 2021, 11, 8428. https://doi.org/10.3390/app11188428
- Chiarelli, P.G.; Martinez, B.; Nakamura, T.; Mis Solval, K. Enhancing Bromelain Recovery from Pineapple By-Products: A Sustainable Approach for Value Addition and Waste Reduction. Foods 2024, 13, 589. https://doi.org/10.3390/foods13040589
- Rathnavelu V, Alitheen NB, Sohila S, Kanagesan S, Ramesh R. Potential role of bromelain in clinical and therapeutic applications. Biomed Rep. 2016;5(3):283-8.

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From Satellites to Soil: New Tech for Monitoring Crops and Forecasting Harvests

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Modern agriculture has seen a significant shift towards the use of remote sensing as a powerful tool, providing timely and accurate information on a large-scale regarding crop health, growth patterns, and potential yields. Farmers and policymakers can make more informed decisions by combining satellite imagery, data from unmanned aerial vehicles, and ground-based sensors to increase crop yields and reduce waste. The combination of remote sensing with crop simulation models and machine learning methods has substantially enhanced yield prediction, drought tracking, and precision agricultural practices. The article examines cutting-edge advancements in remote sensing technologies and their uses in environmentally-friendly farming, as well as discussing the current difficulties and potential opportunities in attaining food security and climate resilience.

Introduction

Agriculture plays a vital role in ensuring global food security, with its productivity being significantly affected by environmental conditions, climate variability, and resource management practices. Effective crop monitoring and precise yield estimation are vital for promoting sustainable agricultural practices, optimizing resource allocation, and reducing the risk of food insecurity. Conventional field-based monitoring techniques have proven effective, they are typically labor-intensive, time-consuming, and constrained in terms of spatial coverage. In contrast, remote sensing has transformed agricultural monitoring by delivering rapid, cost-efficient, and wide-scale insights into crop health, growth patterns, and yield forecasts.

Remote sensing technology employs sensors mounted on satellites, aircraft, and unmanned aerial vehicles (UAVs) to collect spectral, thermal, and radar data, facilitating the evaluation of different crop parameters. Optical sensors, such as those on Sentinel-2 and Landsat satellites, deliver high-resolution multispectral imagery that supports the calculation of vegetation indices like the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI), both of which are extensively used for assessing crop health and estimating biomass. Meanwhile, radar sensors, such as those on Sentinel-1, offer imaging capabilities regardless of weather conditions, making them particularly valuable for agricultural surveillance in areas with regular cloud cover.

Machine learning algorithms, including Random Forest, Gradient Boosting, and Deep Learning techniques, offer more exact yield estimation by integrating remote sensing data with other agro-climatic factors like as temperature, rainfall, and soil moisture. Additionally, hybrid methodologies that combine crop simulation models with parameters derived from remote sensing have demonstrated improved predictive performance across various agroecological zones. This article examines the multifaceted applications of remote sensing in crop monitoring and yield forecasting, emphasizing key satellite missions, vegetation indices, and modeling frameworks. It also explores the integration of machine learning techniques, presents case studies from practical implementations, and discusses emerging trends that are poised to shape the future of precision agriculture.

Remote Sensing Platforms for Crop Monitoring

Remote sensing technologies offer critical data for evaluating crop health, analyzing biophysical attributes, and predicting yields with high spatial and temporal precision (Ali et al., 2022). These platforms are generally classified into three categories: satellite-based systems, aerial platforms such as unmanned aerial vehicles (UAVs), and ground-based sensors

Satellite-Based Platforms

Satellite remote sensing plays a pivotal role in large-scale agricultural assessment by providing consistent and repeatable observations of the Earth's surface. Numerous satellite missions have been specifically designed or adapted for use in agricultural monitoring and yield assessment.

The process of remote sensing via Satellite imagery is portrayed in Figure 1.

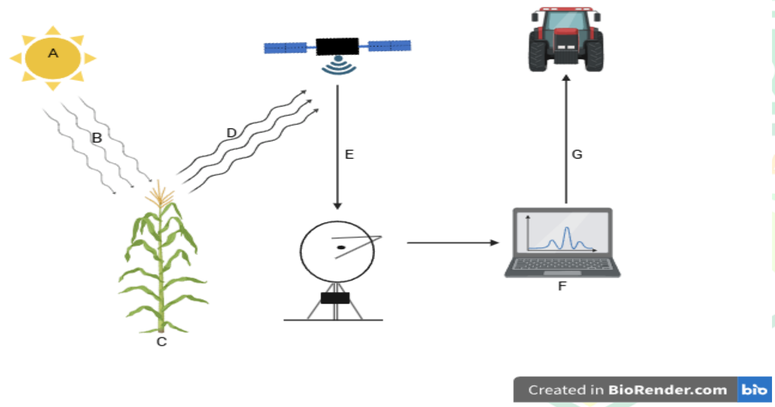

Fig.1. Mechanism of Remote Sensing by Satellite Imagery (Yeshe et al., 2022).

Where,
A: Sun
B: Electromagnetic (EM) energy
C: Plants receiving EM energy, while EM energy is being reflected
D: Reflected energy, detected by the sensors of the satellite
E: Information gathered by satellite is being sent to the ground station
F: Analysis of the information is done
G: The analysed information is plotted on field maps mounted on tractors

Optical Remote Sensing

Optical remote sensing systems capture multispectral and hyperspectral data, enabling the analysis of vegetation properties by examining how plant canopies reflect and absorb light across different wavelengths (Zhang et al., 2020). Prominent optical satellite missions employed in agriculture include:

- **Sentinel-2 (European Space Agency, ESA)** – Delivers high-resolution multispectral imagery with specific bands (e.g., Red-Edge and Near-Infrared) optimized for vegetation analysis.
- **Landsat Series (NASA/USGS)** – Offers a long-term archive of moderate-resolution images suitable for studying agricultural trends over time.
- **MODIS (NASA)** – Though lower in resolution, it provides daily global coverage, making it valuable for monitoring crops on a broad scale.
- **PlanetScope (Planet Labs)** – Supplies high-frequency, high-resolution imagery, supporting detailed observations for precision agriculture.
- **Hyperspectral Missions (e.g., EnMAP, PRISMA, DESIS)** – Capture data across numerous spectral bands, facilitating in-depth analysis of crop types and early detection of stress conditions.

Limitations: Cloud dependency hampers data acquisition.

Radar (SAR) Remote Sensing

Synthetic Aperture Radar (SAR) systems operate independently of weather conditions and daylight, offering reliable data collection even under cloudy or rainy skies. SAR technology is particularly effective for assessing crop structure and soil moisture content. Notable SAR missions include:

- **Sentinel-1 (ESA)** – A C-band radar satellite commonly used for applications such as crop mapping, biomass estimation, and soil moisture analysis.
- **RADARSAT (Canadian Space Agency, CSA)** – Provides SAR data with multiple polarization modes, enhancing agricultural assessments.

• **ALOS PALSAR (Japan Aerospace Exploration Agency, JAXA)** – An L-band radar system that excels in analyzing vegetation structure.

Integrating SAR data with optical imagery enhances the robustness of agricultural monitoring systems, particularly for improving the accuracy of crop yield prediction models.

UAV-Based Remote Sensing

Unmanned Aerial Vehicles (UAVs), or drones, are increasingly utilized in precision agriculture due to their ability to capture ultra-high-resolution imagery and enable flexible, on-demand data acquisition. Equipped with multispectral, hyperspectral, or thermal sensors, UAVs support detailed, real-time crop health assessments at the field level. It offers;

- **High spatial resolution** (centimeter-level).
- **Real-time assessments** and flexible deployment.
- **Precision monitoring** at the field scale.

Methods for Integration

1 Direct Coupling

Remote sensing-derived variables, such as leaf area index (LAI), fractional vegetation cover (FVC), and soil moisture, are directly input into scrop models.

e.g., Using Sentinel-2 LAI data to inform DSSAT's biomass predictions.

2 Data Assimilation Techniques

Data assimilation methods, such as Ensemble Kalman Filter (EnKF) and Particle Filter (PF), integrate remote sensing observations into model simulations to correct uncertainties.

Example: MODIS-based NDVI data is assimilated into APSIM for real-time yield forecasting.

3 Hybrid Modeling Approaches

AI/ML (Random Forest, XGBoost) used alongside crop models.

Example: Correcting DSSAT errors using machine learning.

Applications

✓ Yield Forecasting: Combining Sentinel-2 NDVI time series with DSSAT simulations enhances yield prediction accuracy.

✓ Drought Monitoring: Integration of satellite-derived soil moisture with APSIM improves drought impact assessments.

✓ Climate Change Impact Studies: Remote sensing provides historical climate data for modeling future crop yield scenarios under different climate conditions.

✓ Precision Agriculture: UAV-based imagery is integrated with WOFOST to optimize fertilizer and irrigation management.

Challenges

✓ Data Availability and Resolution: High-resolution satellite data may not always align with the temporal and spatial requirements of crop models.

✓ Uncertainty in Model Parameters: Variability in soil properties and crop responses can introduce uncertainties in yield predictions.

✓ Computational Complexity: Integrating multi-source data into simulation models requires significant processing power.

Crop Yield Estimation for Food Security and Policy Planning

Remote sensing provides large-scale yield estimates crucial for:

Precision Agriculture and Farm-Level Optimization

• Variable Rate Application (VRA)
• Yield Mapping
• Disease/Pest Monitoring

Challenges in Remote Sensing for Agriculture

Data Quality and Resolution: The accuracy of yield estimation relies heavily on the quality and resolution of remote sensing data.

Data Integration and Assimilation: Remote sensing data often comes from various sources, such as different satellite platforms, UAVs, and ground-based sensors, each with varying spatial, temporal, and spectral resolutions (Han et al., 2024).

Model Calibration and Validation: Crop models rely on accurate calibration and validation to provide reliable yield predictions.

Computational and Technical Limitations: The integration of remote sensing with crop simulation models requires substantial computational

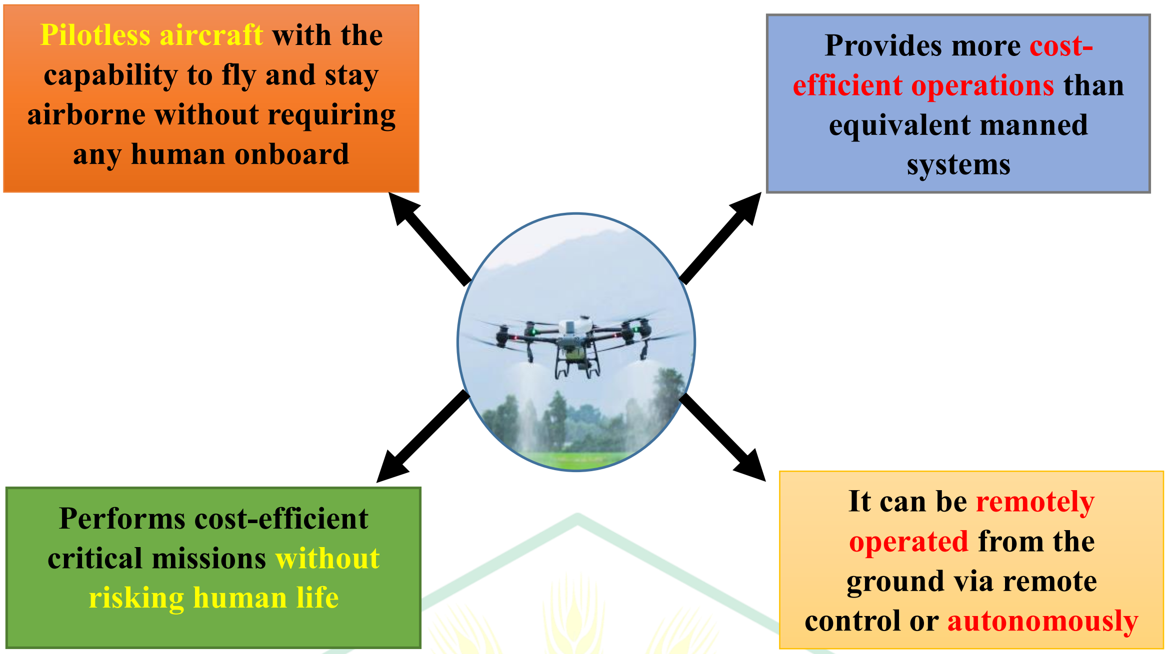

Fig.2. Advantages of UAV (Mohsan et al. 2023)

resources, especially when working with large datasets or real-time monitoring.

Adoption and Awareness: Despite the promising potential of remote sensing applications, the adoption of these technologies among farmers remains limited, especially in developing countries.

Conclusion

Satellite imagery, along with sensors and unmanned aerial vehicles (UAVs), has transformed crop monitoring by allowing for the precise evaluation of crop well-being, stress, and yield forecasting. The integration of artificial intelligence, machine learning, and crop models increases the precision of weather forecasts by utilizing data related to climate, soil conditions, and agricultural practices. Despite hurdles such as data resolution and restricted usage, progress in high-resolution imaging, the Internet of Things, and real-time analytics is clearing the path for globally interconnected, eco-friendly agricultural systems.

References

Ali, A. M., Abouelghar, M., Belal, A. A., Saleh, N., Yones, M., Selim, A. I., Amin, M. E. S., Elwesemy, A., Kucher, D. E., Maginan, S., & Savin, I. (2022). Crop Yield Prediction Using Multi Sensors Remote Sensing (Review Article). In *Egyptian Journal of Remote Sensing and Space Science* (Vol. 25, Issue 3). https://doi.org/10.1016/j.ejrs.2022.04.006

Han, H., Liu, Z., Li, J., & Zeng, Z. (2024). Challenges in remote sensing based climate and crop monitoring: navigating the complexities using AI. In *Journal of Cloud Computing* (Vol. 13, Issue 1). https://doi.org/10.1186/s13677-023-00583-8

Mohsan, S. A. H., Othman, N. Q. H., Li, Y., Alsharif, M. H., & Khan, M. A. (2023). Unmanned aerial vehicles (UAVs): practical aspects, applications, open challenges, security issues, and future trends. In *Intelligent Service Robotics* (Vol. 16, Issue 1). https://doi.org/10.1007/s11370-022-00452-4

Yeshe, A., Gourkhede, P., & Vaidya, P. H. (2022). *Application Remote Sensing (RS) And Geographical Information System (GIS) in Agriculture*. (pp. 237–255).

Zhang, N., Yang, G., Pan, Y., Yang, X., Chen, L., & Zhao, C. (2020). A review of advanced technologies and development for hyperspectral-based plant disease detection in the past three decades. In *Remote Sensing* (Vol. 12, Issue 19). https://doi.org/10.3390/rs1219318.

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Value addition of Spices and Condiments

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The term value added products in general indicates that for the same volume of primary product, a high price is realized by means of processing, packing, upgrading the quality or other such methods.

The advantages of value added spice products are:

1. More volume can be handled per unit area.
2. Encourages growth of ancillary industries.
3. Fetches increased foreign exchang

Whole or ground spices do not impart their total flavour readily. They are bulky for storage and transportation and often unhygienic due to bacterial contamination. Grinding the spice before use releases the flavour principles more efficiently:

The various value added forms:

A. Ground Spices: Have easy mixing or incorporated in food dishes more uniformly but limited shelf life and are subjected to oxidation, flavour loss and degradation on long storage due to microbial contamination.

B. Spices Extractives: Are the alternatives to whole or ground spices? These can be categorized into three groups:

1. Essential oils.
2. Oleoresins
3. Derivatives of essential oils and oleoresins.

1. Essential oils: Are the aromatic, volatile components present in most spices? They are primarily obtained from plant material by steam distillation. Essential oils have uniform flavours' quality and are free from enzymes and tannin. They do not impart colour to the end products.

2. Oleoresins: The spice oleoresins are obtained by extraction of the dry ground spices with an organic solvent mixture such as ethylene chloride acetone, hexane or alcohol. It contains all the volatile as well as non volatile constituent of the spice, closely re[resents the total flavour of the fresh spice in the concentrated form.

3. Derivatives of essential oil and oleoresins:

I) **Encapsulated form-** They tiny particles of spice extract coated with an envelope of starch or gum, so that the flavour is locked within capsules. When these products are incorporated in food the outer coating is dissolved and the flavour is released.

II) **Seasoning in dry carriers-** Such as dextrose salt or husk powder. These are blends of various extractives, either in liquid or dry form.

III) **Emulsions** – Emulsions are prepared by emulsifying essential oil and oleoresins with gums and other emulsifiers.

C. Curry powder: It is indigenous seasoning made from a blend of various (may vary from 5 to 20 depending on its end use) namely Turmeric, Ginger, Chillies, Coriander, cumin, fennel, fenugreek, black pepper, clove etc. constitute the raw material used in quality curry powder.

D. Consumer packed spices: Packaging has gained considerable importance as it increased the shelf life of spices. The popular media are glass bottles, rigid plastic containers, metal containers and flexible pouches. By exporting consumer packed spices, higher unit value for the same quantity can be earned.

E. Processed spices: The processed value added spice products are dehydrated. Frozen or freeze dried green pepper and canned pepper in brine.

F. Organic Spice: The growing demands for organic crop product have led to the development of international trade for organic spices. India is now one of the country exporting organic spices.

Major value added spice products:

Spice	Product
Cardamom (large)	Oil, oleoresin
Cardamom (small)	Oil, oleoresin, Green cardamom
Black Pepper	Oil oleoresin, Green Pepper in brine, dehydrated green pepper, frozen green pepper, white pepper, ground pepper, organic paper, canned tender, green pepper
Turmeric	Dehydrated turmeric powder, Cureminoids, oil, oleoresin
Ginger	Oil oleoresin, candy, preserves, various forms of ginger powder, ginger brandy, wine, beer, Medicinal beverages, encapsulated ginger oil, and dehydrated ginger
Chilies	Chilli powder (pungent and non pungent), green chilly in brine, canned green Chilli, Chilli paste, pickles, capsicum oil and oleoresins
Coriander	Coriander powder, Organic coriander, dried coriander leaves, oil and oleoresins
Fennel	Fennel powder, sugar coated fennel, whole seed, organic fennel, fennel brandy, wine and beer, medicinal beverages, fennel sip, oil and oleoresins
Cumin	Cumin powder- medicinal beverages, cumin sips, organic cumin, oil and oleoresins

Factors which affect the quality of seed spices:

A. Effect of production Practices: The major thrust of seed spices was on higher production and productivity. However the quality consideration was generally very poor. Perhaps it was due to several factors.

1. Immediate benefits to the farmers attained through yield increase.
2. Scientific grading based on intrinsic quality did not exist. So the marketing of seed spices with different level of quality did not fetch differential prices.
3. Lack of understanding of the elusive characters of quality.
4. Lack of facilities to evaluate quality objectives.

B. Effect of climatic conditions:

1. The role of climatic conditions on the biosynthesis is pattern of volatile oil constituents in seed spices is well known. Cooler and drier climate of Northern Europe produce more of linalool in coriander than tropical climate of India.
2. Fruit ripens at high humidity, volatile oil contends in the fruit may be high but its organoleptic, quality is poorer due to less linalool contents and more aldehyde contents.
3. In fennel, the cold weather is favourable. Hence it is grown in north part of India. It does not thrive in Southern part of India except at high elevation. A dry and cold weather favours higher seed production.

C. Effect of soil fertility: Seed spices grow under wide range of conditions but thrive best on a medium to heavy soil in sunny location with good drainage and well distributed moisture Coriander is usually grown as rain fed crop. Coriander is also grown on rich silt loam of Northern India. Heavy black, clayey cotton soils as occur in Deccan and South India are also found to be suitable for coriander cultivation.

Judicious use of fertilizer has been shown to benefit the volatile oil contents as well as seed yield of coriander. For fennel all types of soil except sandy soil is recommended. However, loamy or black soil with good drainage, with sufficient nutrient is most suitable for cultivation. A fertilizer dose of 15kg/ha as top dressing was recommended for higher yield.

D. **Effect of Weed**: Adulteration of weed to the spices affects the quality. The presence of weed seed like Zeeri (Plantago pumila W.) and Parijan in cumin seed was found to fetch fewer prices. Zeeri plant, a serious weed of cumin, cannot be distinguished from the cumin plant up to the stage of flowering. Volatile oil and test of cumin was reduced due to presence of weed.

E. **Effect of diseases**: Diseases like wilt, blight and powdery mildew in cumin, wilt, powdery mildew and stem gall in coriander, Blight and gummosis in fennel; and powdery mildew, and MLO in fenugreek frequently attack these crops causing heavy loss of yield and deteriorate the quality of the produce.

F. **Effect of proper marketing system:** Non-existence of regulated market facilities for seed spices crops affect quality of the produce. This may be overcome by.

1. Creation of produce collection center.
2. Installation of grading machines and sun driers for categorizing the produce.
3. Creation of the processing units in area of high density production.