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Significance of Vegetable Processing for Preservation and Nutritional Security



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Introduction

World is seeking for food and nutritional security for a peaceful and healthy society, food security exists when “all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meet their dietary needs and food preferences for an active and healthy life”. The other important aspect is nutritional security that exists when “secure access to an appropriately nutritious diet is coupled with a sanitary environment, adequate health services and care, in order to ensure a healthy and active life” (FAO, IFAD, & WFP, 2015). India holds second position in global vegetable production after China and produces 209.39 million tonnes of vegetables as per National Horticulture Database (1st Advance Estimates) published by National Horticulture Board 2023-2024 (APEDA, 2025). Despite such elevated levels of production, post-harvest losses are staggering, ranging from 25-40% worldwide and approximately 30 % in India. Simultaneously, the global population is projected to soar exponentially, reaching as high as 10 billion by 2058 (Chamie, 2023). Also, this era is marked by a surge in non-communicable diseases (NCDs), numerous epidemiological studies have shed light on reduction of the prevalence and risk of these health conditions and degenerative diseases, by incorporation of vegetables and fruits in the diet owing to the diverse range of phytochemicals involving antioxidants and bioactive compounds (Chen et al., 2020). Consequently, post-harvest processing treatments serve as pivotal factors in extending the storage duration and market viability of perishable horticultural produce. Thus, there is an urgent necessity to process vegetables not only to meet the demands of this expanding population qualitatively and quantitatively but also to reduce the significant post-harvest losses. Food processing is set of operations which are done to bring some deliberate changes in the raw material to make them more useful, shelf-stable, palatable and acceptable by the consumers (International Food Information Council Foundation, 2010). The main aspects that are targeted by the processing are preservation, food safety, changes in flavour, colour, form, texture, restoration or increase in nutrition, added convenience and portability.

Advantages of vegetable processing

1. **Reduction of Wastage and Losses:** Vegetable industry, integral to horticulture, plays a crucial role in addressing inevitable waste despite improvements in distribution and marketing of fresh produce.
2. **Handling Glut:** Processing allows for the utilization of surplus produce during glut seasons, thereby reducing wastage and efficiently managing excess yield.
3. **Stabilizing Farm Prices and Income:** By incorporating excess produce into value-added products, that contributes to stabilizing farm prices and providing additional income to farmers.
4. **Utilizing Marketable Surplus:** The processing industry efficiently utilizes both marketable surplus and substandard produce, ensuring profitable returns for growers.
5. **Generating Employment:** As a labour-intensive sector, fruit and vegetable processing creates both direct and indirect employment opportunities, contributing to economic growth.
6. **Dietary Variety:** Value addition through processing enhances the attractiveness and palatability of food, thereby adding diversity to the diets.
7. **Ensuring Nutritional Security:** Improved processing prospects help in maintaining the nutritional properties of the produce.
8. **Foreign Exchange Earnings:** The processed fruit and vegetable export contributes to earning foreign exchange, fostering economic sustainability.

Key processing techniques in vegetable processing

Sorting/Grading: The sorting process post-harvest involves the meticulous removal of diseased, damaged, misshapen, over-mature, insect-infested, and rotten vegetables. Any produce affected by disease or insects should be promptly discarded to prevent the potential spread and contamination of healthy fruits and vegetables.

Washing: The purpose of washing produce is to eliminate clinging dirt, dust, insects, mould, and any residual sprays, thereby enhancing their appearance and hygiene. However, certain items like onions, garlic, okra, and mushrooms are typically not washed post-harvest. For surface decontamination, mild cleaning agents such as soap solution, glacial acetic acid, or a 1% NaCl solution can be used. Alternatively, chlorinated water (100- 150 parts per million chlorine) proves effective for this purpose.

Curing: The process of treating specific root, bulb, and tuber vegetables aims to promote the healing of wounds and facilitate the drying of outer tissues. This critical step is essential to minimize water loss and prevent disease infection during their subsequent storage. Scientifically, this treatment, often referred to as suberization, involves the application of protective compounds or coatings on the wounded surfaces.

Packaging: Packaging involves enclosing produce within a suitable packing material, such as plastic films, moulded trays with cushioning pads, crates and wooden boxes. Its primary aim is to prevent movement and safeguard the produce. This protection can be achieved using materials like breathable plastic films, waxed liners, etc.

Freezing: Freezing is a process of subjecting the produce to a temperature below its freezing point resulting in a decreased rate of deterioration by changing the state of the water present inside the vegetables from liquid to solid rendering immobilization of water and by soaring the solute concentration deterioration (Jha et al., 2017).

Canning: Canning is an important processing technique of heat preservation of the vegetables in hermetically sealed containers by dipping it in brine solution. Canning is often called as appertization (Sharma, 2010). Canning is an efficient technique to preserve vegetables especially in the countries where the refrigeration facility is very limited or non-existent as the canned commodities can be kept at room temperature for months and years together.

Drying: Vegetables undergo dehydration primarily by utilizing heat, whether it stems from the sun's radiant energy or from air heated through electrical means. A key benefit of this dehydration process is the diminished volume and weight of the vegetables, facilitating the storage and transportation of the dried products.

Processed vegetable products for vegetable preservation

Tomato ketchup/ sauce: Tomato ketchup is a popular Indian condiment prepared by processing the tomato paste with certain spices till a specific TSS is reached, it is commonly utilized as a dipping sauce for snacks like French fries, samosas, and pakodas. Additionally, it functions as a flavoured topping for an array of dishes, including burgers, sandwiches, cutlets, and rolls. Research from the National Institute of Nutrition (NIN) reveals that approximately 70% of Indian households consumes tomato ketchup as a regular culinary practice. Moreover, it is approximated that the average annual consumption of tomato ketchup per individual in India amounts to around 5.5 kg, based on the findings of the survey by Shinde et al. (2023).

Pickles: Vegetable preservation using common salt or vinegar is known as pickling. It encompasses usage of fermentation technology by predominantly lactic acid-forming bacteria which are generally present in large numbers on the surface of fresh vegetables and fruits. It is one of the primitive techniques of preserving vegetables that adds palatability to food and also acts as an appetizer. Typically, pickled vegetables include onion, turnip and carrot where brine strength of 10-12% is sufficient to reduce most of the spoilage causing bacteria .

Sauerkraut: Sauerkraut is basically fermented cabbage and it literally translates to acidic cabbage. The intrinsic microflora of cabbage is used for fermentation and it is majorly consumed in the central and southern Asia, Europe and the United States. This product has health benefits owing to the inflammatory properties, cholesterol reduction properties in dyslipidaemia and a wide array of phytonutrients antioxidants, vitamins A and C present in the cabbage (Enwa, 2014).

Preserve/ candy: Preserve is usually prepared by impregnating the vegetable as a whole or in pieces with heavy sugar syrup till it becomes saturated with the solute concentration. The principal of preservation here is removal of the water from the commodity that is facilitated by addition of solute in the preserve.

Pickled Gherkins: Cucumbers boast a wealth of polyphenolics and cucurbitacins, renowned for their diverse biological activities, including antioxidant, anti-carcinogenic, anti-hyaluronidase, anti-elastase, anti-

inflammatory, anti-hyperglycemic, diuretic, amylolytic, antimicrobial, and analgesic effects. Gherkins are pickled cucumbers that not only enhances flavour and texture of the cucumbers but also increases the nutritional qualities which facilitates in increasing its health-promoting potential. This is particularly notable in addressing complications related to diabetes and cardiovascular disorders, attributed to the presence of monounsaturated fats and other valuable minor components like phenolics (Uthpala, 2020).

Vegetable soup: The soup production industry is rapidly evolving globally, marked by a diverse and expanding array of value-added soup products that offer both a homemade taste and convenient ready-to-eat options. Various vegetables, leafy greens, tubers, bulbs, legumes, and herbal extracts serve as key components in soup formulation. These ingredients not only contribute to the rich flavour but also provide essential nutrients such as fibre, vitamins and minerals. Additionally, they encompass a broad spectrum of compounds that play a role in promoting overall health and well-being (Fernández-López, 2020).

Ready to cook vegetable-based convenience mix: Vegetable based convenience mixes are rapidly gaining popularity owing to their ease of use, these mixes include kheer mix, porridges mix, cheela mix etc. which provide the consumer the luxury of nutrition as well as convenience. Several convenience mixes have been developed based on dehydrated and fried vegetables and other ingredients. The vegetable curry mixes are quick to cook and retain the delicate taste of Indian culinary preparation with a shelf life of over nine months.

Conclusion

The vegetables are capable of protecting the cells and prevent tissue degeneration caused by various diseases owing to myriad of several phytochemicals present in them especially anti-oxidant compounds present in them. vegetables have carotenoids which are also present in human blood and tissues, the major carotenoids in blood and tissue are β -carotene that are found in a number of vegetables in optimal amount. Thus, vegetable processing is an essential link for nutritional security. As the global challenge to feed safe and nutritious vegetables to the growing population by 2025 cannot be met by merely improvement in the vegetable production, processing of vegetable should also be emphasised as a sustainable and key strategy for countering losses in terms of production and nutrition for all. Also, there is need to address the dynamic preferences of the demography, in which processing of vegetables can play a key role.

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Aptamers as targeted therapeutics for bacterial disease diagnosis in the livestock sector



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Introduction

Aptamers are short oligomers of nucleic acid molecules that can serve as potential substitutes for antibodies, as they can be synthesized chemically and exhibit specificity like antibodies to capture antigens for equivalent identification. Aptamers offer potential benefits over antibodies, including smaller size, simplicity, and robustness in handling, as well as lower manufacturing costs and stability. Due to these advantages, they are often considered as synthetic antibodies. In certain scenarios, aptamers compete with monoclonal antibodies for lower immunogenicity, higher specificity, and simplicity in vitro selection. SELEX (Systematic Evolution of Ligands by Exponential Enrichment) is the best approach to produce aptamers that can last from several weeks to months. Schematic representation of SELEX has been shown in the figure 1. Aptamer-based apta-sensors have been developed for targeting the analytes, pathogen detection, and immunophenotyping. As a result, it becomes essential to detect drug residues and animal illness. There are various bacterial diseases, such as enteritis, tuberculosis, and mastitis, which are affecting the farmers' economies due to higher prevalence rates in the animals.

Diagnosis of bacterial diseases

Enteritis

In livestock animals, *Escherichia coli* are found abundantly in the intestinal gut flora and can survive in multiple abiotic environments. Although *E. coli* benefits the host after colonizing the gastrointestinal tract of infants, it can cause potential disease like enteritis due to its adaptability to different niches, high disease-causing ability, and higher mortality rates (1). Several types of *E. coli* are responsible for affecting the gastrointestinal tract: diffusively adherent *E. coli* (DAEC), enterohemorrhagic *E. coli* (EHEC), enteropathogenic *E. coli* (EPEC), and entero-invasive *E. coli* (EIEC). Various *E. coli* aptamers like E18RSSDNA aptamer (2), E1 aptamer (3), P12-55 SSDNA aptamer (4), E2 SSDNA aptamer (5), and EcA5-27 aptamer (6) were reported to bind against specific *E. coli* species like *E. coli* O157:H7, *E. coli* ATCC 25922, *E. coli* KCTC 2571, and *E. coli* NSM59, respectively. A1/AUNP-anti-Ecoli O157:H7 aptamer binds specifically to the *E. coli* O157:H7. Microchip capillary electrophoresis-based aptamer binding was used for the detection of O157:H7 by coupling with laser-induced fluorescence.

Tuberculosis

In bovines, the most common bacteria causing tuberculosis are *Mycobacterium bovis* (*M. bovis*). Tuberculosis is a slow-progressing disease primarily caused by *M. bovis* and, to a lesser extent, by *M. tuberculosis* and *M. caprae*.

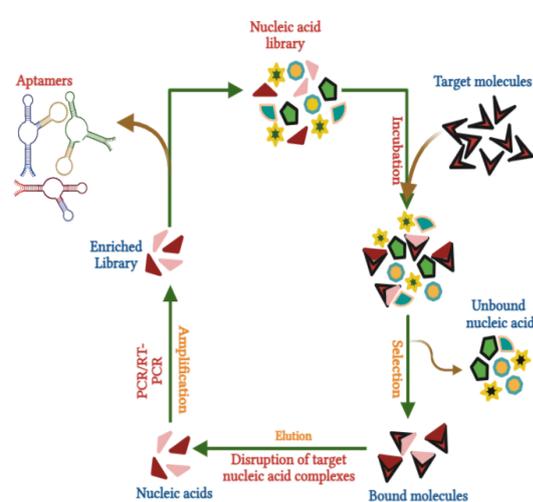


Figure 1: Schematic representation of SELEX

M. bovis is also the main responsible pathogen for respiratory diseases, mastitis, and arthritis. Due to a compromised conventional approach, serological detection of *M. bovis* is more challenging. A competitive indirect enzyme-linked aptamer assay (ELAA) has been used to detect *M. bovis* using a single-stranded DNA (ssDNA) aptamer WKB-14 (7). The tuberculin skin test is the most traditional and standard diagnostic test in livestock, but it is a time-consuming process that takes around eight weeks or more. As a result, aptamers were designed for POC diagnosis for the detection of tuberculosis. Single-stranded DNA aptamers designed using SELEX procedures detect *M. tuberculosis* H37Ra. The diagnosis of *M. tuberculosis* in bovines is difficult to detect due to delayed symptoms. Bovine interferon gamma (BoIFN- γ) released by T-cells can offer a potential diagnostic marker for detecting *M. tuberculosis* (8). A volumetric apta-sensor can be used to detect ESAT-6, a secretory antigen secreted by *M. tuberculosis*.

Mastitis

Bovine mastitis is the most common and deadly disease in dairy cows, caused by the inflammation of the mammary gland. In India, the estimated economic loss due to clinical and subclinical mastitis is around US\$98,288 million (7165.51 crore Indian Rupees) (9). It is the most prevalent disease in buffalo and cattle, complicating the production and processing of milk, compromising the quality of milk and its byproducts, which leads to severe economic losses to the dairy sector. The most common mastitis-causing pathogens are *Staphylococcus aureus*, *E. coli*, *Mycoplasma spp.*, *Streptococcus spp.*, and *Pseudomonas spp.* etc (10). A magnetic bead and antibiotic-capped gold nanocluster aptamer have been developed for detecting bacteria causing mastitis. SOMAmer (slow off-rate modified aptamer) has been designed to detect *S. aureus*. SOMAmers are ssDNA (<30nm) that contain pyrimidine residues and have long dissociation rates (11). SpA and Clf ASOMAmers are the selective aptamers for the detection of *S. aureus*. ELONA (Enzyme-Linked Oligo Nucleotide Assay) is used to detect the protein A-binding aptamer PA#2/8 in *S. aureus* (12).

Conclusion

Aptamers are gaining prominence in research laboratories due to their versatility in several medical applications, including drug efficiency, disease diagnosis, and bacterial detection. The techniques developed from SELEX innovatively pave the way for detection, diagnosis, and treatment approaches that serve as an alternative to traditional antibody-based detection systems. Due to its potential benefits, it is used as a novel biosensor in imaging and detecting bacteria. It is crucial to optimize the ongoing research on the aptamers and prioritize their development to bind specific targets. Therefore, the aptamer-based biosensors discussed in this article contribute comprehensive insights into bacterial disease diagnosis.

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Asian Giant Hornet, *Vespa mandarinia* Smith: A major menace to honeybee colonies



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1. Introduction

Asian giant hornet, *Vespa mandarinia* Smith (Insecta: Hymenoptera: Vespidae) holds the title for being the world's largest hornet. Commonly referred to as the Asian giant hornet, *Vespa mandarinia*'s unrivaled size and distinctive markings make it easily distinguishable from other Asian hornet species (Figure 1). This wasp's sting can be life-threatening to humans and it can decimate a number of insect colonies, most notably wild and managed honey bees (Matsuura and Sakagami 1973). Asian giant hornet is native to Japan and can also be found established outside of its native range in several countries in Asia, in both temperate and tropical climates.



Figure 1. Female *Vespa mandarinia* Smith, resting. Photograph by Yasunori Koide, Wikimedia commons.

2. Distribution:

Asian giant hornet is native to temperate and tropical eastern and south-eastern parts of Asia including Thailand, China, Nepal, Russia, and its native Japan. Currently, this species is not established in western Europe, but sporadic records of its occurrence have been reported in several countries (Pest Tracker 2017). These hornets prefer to nest in temperate regions, including mountainous areas, but can also be found in some and throughout the Himalayas, parts of the Russian Far East and North Japan (Matsuura and Sakagami 1973). A colony of Asian giant hornet was discovered in September 2019 in British Columbia, Canada. This was the first colony found in North America. In the United States, the first appearance of this hornet was reported in the early Fall 2019. The first specimen was collected in December 2019 in Blaine, Washington. Regular monitoring and trapping efforts in Washington will be conducted to note any further occurrences and risk of distribution.

3. Description

Vespa mandarinia is the largest hornet species in the world. Adult workers body length is from 25 to 40 mm and queens can exceed 45 mm. Asian giant hornet individuals are large and robust wasps with several distinctive features that distinguish them from other similar species. There are 23 species of hornets known so far, of which 15 are found in India. The head is wider than other Asian hornet species, specifically above the mandibles and between the eyes. The front of the face above the mandibles (the clypeus) has a deeply scalloped edge, rather than being evenly rounded. The cheeks (genae) are pronounced on both sides of the head, making the head appear noticeably wider in full face view (Figure 2). The genae house the muscles needed to power the large mandibles that play a vital part in the ability of *Vespa mandarinia* to overpower prey (Matsuura and Sakagami 1973). Adult workers are often slightly shorter than 5.08 cm (2 inches) in length whereas adult queens are close to 5.08 cm (2 inches) (Figure 3).



Figure 2. Asian giant hornet anterior view of head.

Adults have an overall matte orange-yellow colored head (Figure 1). Banding on the abdomen is yellow and brown, with the last segment uniformly yellow (Figure 3).

The head, thorax and abdomen are stout and have varying densities of setae (hairs). In addition to compound eyes, these hornets, like other Hymenoptera, have ocelli (the three light sensing organs between the eyes). The possession of the stinger distinguishes female reproductives (queen) and non-reproductive workers from the stingless males. The stinger is smooth and nearly a centimeter in length. As is characteristic of all Hymenoptera, this hornet has two pairs of wings with the forewing surpassing the body length of 5 cm (2 inches) (Figure 3).



Figure 3. Asian giant hornet female adult length

4. Life Cycle and Biology of Asian giant hornet

All Asian giant hornet colonies are established in the spring by mated queens after they have emerged from diapause (period of postponed development). These queens feed on tree sap for energy and first scout for a proper space to start a colony. Once a queen has selected an adequate location, often in a cavity or hollow area near the roots of trees, she begins constructing the comb from woody materials gathered while foraging. These fibers are then manipulated into cells and surrounding comb with her mandibles. To accommodate the growing colony, these hornets will excavate additional space by removing balls of soil with their mandibles.

The queen is solely responsible for the development and safeguarding of the colony. She continues to provide food and protection to her brood until workers begin to emerge. After worker emergence, the workers primarily take over these duties while the queen is dedicated to egg laying in the 1000 or more cells of its typically large nest.

Larval Asian giant hornet develop through five larval instars (stages), during which time they are fed either bits of prey tissue or tree sap. After completing larval development, each individual pupates within the covered cell and remains in a cocoon for nearly 18 days. The colony size ranges greatly from 4 to 12 comb panels and as many as 3000 distinct cells (Matsuura and Yamane 1990). Each comb lies mostly horizontal, conforming to the available space. The nest cover is often unfinished and consequently the last comb located at the bottom of the nest structure is exposed. These brood cells can vary slightly in depth and width depending on whether they were constructed by the queen or workers. Worker cells have an average diameter of approximately 11 mm while both queen and male cells are 14 mm in diameter. The depth of these cells ranges from approximately 33 mm for workers to 42 mm for queens (Matsuura and Sakagami 1973).

Colonies grow during summer and into fall until a brood of reproductive females (new queens or gynes) and male hornets emerge around the end of October. These male hornets leave the nest and will wait outside nest entrances to mate with new queens emerging from nests. Once the new queens mate, typically with only one male, they begin to search for an ideal overwintering site in the soil where they will remain for nearly seven months before starting their own colonies in the spring (Takahashi *et al.* 2004). In late fall, around mid-November, founding queens die, and the original colony quickly weakens as workers die off and are not replaced.

5. Predatory Strategies by Asian giant hornet

Asian giant hornet workers have a more extensive foraging range than other hornet species. They tend to attack prey located within two kilometers from the nest but have been noted to travel as far as eight kilometers in search of food. These hornets are very assertive when competing for resources during the spring months. For example, *Vespa mandarinia* nestmates will congregate around the sap supply on a tree and prevent other hornet species from feeding. Insect prey is a vital source of protein for the growing larvae



Figure 4. Asian giant hornet processing its honey bee prey capture.

in the nest and *Vespa mandarinia* most often preys on large beetle species. If accessible, this hornet also preys on honey bees and other wasps among other insects.

Asian giant hornet utilizes a pair of attack strategies to hunt other social insects. For example, the lone hunting mode involves a single hornet worker capturing one honey bee at a time outside the beehive entrance. The hornet kills the bee by detaching the head from the rest of the body at the thorax (Figure 4), then chews it into a gummy paste for transportation back to the nest where it is fed to larvae. Hornets take bees from multiple colonies rather than concentrating on one specific colony. This mode of hunting can inflict minor or major damage to the colonies depending upon the honey bee species, where multiple species exist in its native range. Similarly, another invasive wasp species *Vespa velutina* attacks honey bee colonies in this way, weakening about 30% of honey bee hives.



Figure 5. Asian honey bees, *Apis cerana*, defensively “balling” a single Asian giant hornet

The most famous mode of predation by this hornet, often referred to as a slaughter, it is extremely damaging to the prey colony.

The slaughter strategy involves groups of 10 to 20 or more Asian giant hornet nestmates staging a coordinated attack on a single colony by ripping multiple guard bees apart (typically at the head) with their mandibles until no individuals remain to defend the nest entrance (Figure 3). An entire honey bee colony of about 30,000 individuals can be destroyed in several hours with the remains of those workers being left in and around the hive. If there are still survivors come nightfall, the hornets will retire to their nest and reappear the next morning to continue their attack until occupation is complete. Once the majority of the bee workers are destroyed and unable to defend the nest, the hornets retrieve the bee larvae and pupae to feed the nest larvae. These types of invasions typically occur in the late summer months when the hornet colonies have produced many workers (Matsuura and Sakagami 1973).

European honey bees, *Apis mellifera*, are practically defenseless against this predator as they have not evolved strategies to defend their colonies. Honey bee stings are ineffective at deterring the hornet as *Vespa mandarinia*'s robust cuticle is not susceptible to these stings. Asian honey bees, *Apis cerana*, have evolved a stronger group tactical technique because of their historical co-existence with *Vespa mandarinia*. The bees communicate to each other to begin surrounding (or “balling”) the hornet in order to raise their group temperature to approximately 46°C (Figure 5), which is high enough to kill the hornet but not kill themselves

The Asian giant hornets primarily feed on larger insects, other eusocial insects, tree sap, and honey bees. However, honey bees are easy targets. The worker hornets wait at the hive entrance, capture the foraging bees, cut apart their head and abdomen and carry the nutritious thoracic region of the bees to their nest for mass provisioning of their broods. Usually, one hornet can hunt up to 40-60 bees in its hunting phase and 120-150 bees in its slaughtering phase. If the bee colony is weak, the hornets enter the hive, collect grubs, pupa and honey from the hive and abandon the empty and weak colony.

6. Economic Importance

Management of Asian giant hornet is quite difficult because of the stinging risk and lack of accessibility to the nests. In the past, Japanese inhabitants have used physical elimination as well as chemicals to kill and reduce Asian giant hornet colonies, though they are difficult to locate and kill below ground. Insecticides such as ready-to-use aerosols and concentrates are utilized by the U.S. Department of Defense in efforts to control other species of oriental hornets. Some beekeepers have taken to using mechanical devices including specially designed screening to assist with defending and protecting the bees at the hive entrances. While there are homemade devices used by some beekeepers in Europe, there are also commercial products such as false bottom boards that trap hornets attempting to invade managed honey bee hives.

Sustained monitoring efforts should be employed for early detection of *Vespa mandarinia* in a region and evaluation of its potential establishment. This species has the potential to negatively impact human health and honey bee colonies, particularly managed *Apis mellifera* (Matsuura and Sakagami 1973). As honey bees play a

significant role in the pollination of crops, establishment of Asian giant hornet in the United States could have a severe impact on agriculture and the economy as well as on human health. Continuous monitoring and subsequent elimination of any discovered colonies is paramount to prevent Asian giant hornet establishment

8. Conclusion

The Asian giant hornet has emerged as one of the most hazardous enemies of honey bees in recent years, and producers are facing a massive economic problem as a result of direct colony loss, reduced honey supply, and high labor costs for manual hornet striking. farmers to reduce the menace of the hornets and improve the economic yield of honey. Moreover, further modifications in the trap design, refining of the bait materials, and making the bait more attractive to the hornets can pave a path for a future line of work.

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DIGITAL JOURNALISM IN AGRICULTURE



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Introduction

The rapid and worldwide flow of information in the form of news, the development of the internet and social media as major channels for communication made this era to be known as Information Age. Journalism has long been regarded as a powerful instrument of change and a critical voice in shaping the nation's narrative. From its role in the freedom struggle to its impact on contemporary society, journalism plays a pivotal role in India's socio-political landscape. Journalism is the backbone of India's democracy, upholding the principles of free speech and expression enshrined in the Constitution and Journalists play a vital role in informing citizens about government policies, political developments, and societal issues. Disseminating information and knowledge to the public. (<https://www.gkftii.com/blog/importance-of-journalism.html>)

Journalism has taken many forms through the evolution of media. One of the ongoing eras for Journalism is Digital Journalism, which stems from its capacity to provide real-time reporting, which enables information to be made unprecedentedly quickly and effectively available to a global audience. According to Jan Van Der crabben, Online journalism can be defined as gathering information, reporting the of facts produced, processed and distributed via internet technology and publish in cyber space”.

Dishant (2020) studied that majority (90.68%) of the KVK scientists used WhatsApp for seeking and dissemination of information, followed by Facebook (76.40%). Similar trend was observed with respect to usage of social media for transfer of technology, in the order of WhatsApp (91.93%), followed by Facebook (52.17%) and YouTube (45.34%). Evidently, WhatsApp stood first among the various purposes for which social media was used by KVK scientists. The other two social media platforms used effectively by the majority of the scientists for all the purposes mentioned in the study were Facebook and YouTube. Svenja and Julia (2023) inferred that 59 per cent of the statements were pro followed by contra (23.40 %) and neutral (17.60 %) with respect to agriculture articles selected for the study. Majority of pro statements used regarding advantages of digitalization of agriculture were work facilitation (10.20 %), reduced use of fertilizers and plant protection (8.90 %) and more environmental protection and sustainability (8.30 %). Statements like insufficient network coverage (3.70 %), great power of providers (2.90 %) and digitalization transforms agriculture (7.90 %) were contra and neutral statements, respectively.

Role of Digital Journalism in Agriculture

Digital Journalism has also taken Agriculture in its whirl and made agriculture information handier and easily accessible to farmer and other stakeholders. The use of digital journalism in agriculture can have significant impacts on productivity, sustainability, and community engagement.

- ❖ **Dissemination of Agricultural News:** Digital platforms offer immediate access to agricultural news, market trends, and policy changes, enabling farmers and agribusinesses to make informed decisions quickly
- ❖ **Community Engagement:** Digital journalism can highlight stories from within the farming community, showcasing successes, challenges, and innovative solutions. This storytelling aspect can foster a sense of community and shared learning among farmers and rural stakeholders
- ❖ **Innovation and Technology Adoption:** Stories and reports on the latest agricultural technologies, such as precision agriculture, biotechnology, and smart farming solutions, can encourage farmers to adopt new practices that increase efficiency and productivity
- ❖ **Policy Advocacy and Awareness:** Reporting on agricultural policies, subsidies, and regulations can inform and mobilize stakeholders to advocate for policies that support sustainable and profitable farming practices
- ❖ **Crisis Communication and Management:** In times of agricultural crises, such as pest outbreaks, natural disasters, or disease epidemics, digital journalism can provide critical information and guidance to affected communities swiftly

- ❖ **Education and Training:** Through articles, blogs, and videos, digital journalism can provide farmers with educational content on best practices, new technologies, sustainable farming techniques, and crop management strategies
- ❖ **Weather and Climate Information:** Real-time weather updates and climate forecasts are crucial for agricultural planning and risk management. Digital journalism platforms often integrate weather data to help farmers make better-informed decisions about planting, irrigation, and harvesting.
- ❖ **Market Access and Price Information:** Digital journalism platforms can offer farmers access to current market prices for crops and livestock, helping them decide when to sell their products and at what price, thus maximizing their profits
- ❖ **International and Cross-border Information Sharing:** Digital journalism transcends geographical boundaries, enabling the exchange of agricultural knowledge, practices, and innovations across different regions and countries
- ❖ **Research and Development:** Coverage of the latest research findings and development projects in agriculture can facilitate the transfer of knowledge from researchers to practitioners, promoting the adoption of evidence-based practices

Role of Extension Professional in Digital Journalism

Extension Professionals play a crucial role in bridging gap between agricultural researchers and farmers. They are often at forefront to introduce new technologies, practices and products. Along with the dissemination of knowledge, they empower farmers with information and tools needed in a rapidly changing world.

i. Determining what audience need: Identifying the critical information, guidelines and resources according to the farmers need.

ii. Identifying credible content to share: Transferring the research data into understandable and actionable information from credible sources so that it is relevant to conditions of farmers.

iii. Recognizing the platforms audience used by the audience/ farmers and which kind of message is comfortable and suitable for which outlet is one of the important roles of extension professional.

iv. Establishing goals and strategies appropriate to selected platforms: Deciding the kind or type of data to be disseminated to which farmers through multiple outlets

v. Experimenting and Mastering use of platforms for engagement: Conducting webinars, workshops, training sessions to disseminate the information to different regions.

vi. Crafting a message for multiple outlets: Contributing in the form of written articles producing videos and other forms for practical advice for farmers

Digital news platforms avenue to receive feedback directly from farmers and help tailoring extension activities to better meeting of farmer need.

Advantages and Disadvantages of Digital Journalism

Digital platforms allow news to be accessible to a global audience, breaking geographical barriers and enabling instant access to information. Digital platforms can reduce the costs associated with printing and distribution, allowing for resources to be allocated to investigative reporting and coverage. The use of data in storytelling and the availability of analytics allow journalists to uncover stories hidden in data and understand audience behavior better.

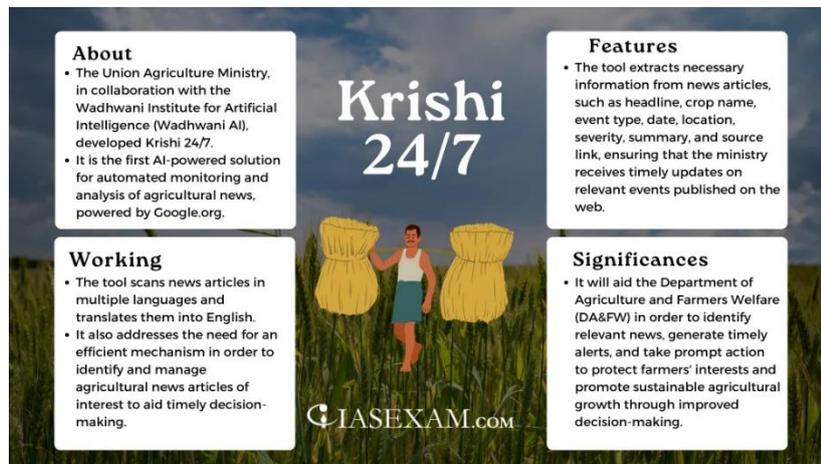
The sheer volume of content available online can overwhelm readers and make it difficult to distinguish important news from trivial information. The pressure to publish quickly and the emphasis on quantity over quality can lead to superficial reporting, with less investigative depth and thoroughness. The proliferation of sources and the challenge in verifying information can erode trust in media, as audiences find it difficult to discern credible journalism from biased or false information.

Examples for Digital platform in Agricultural Journalism

Krishi 24/7:

The first-ever AI-powered solution for automated agricultural news monitoring and analysis, with support from [Google.org](https://www.google.org). This innovative system was created through a collaborative effort between the DA&FW, the Wadhvani Institute for Artificial Intelligence, and received support from Google. The tool **scans news** articles in multiple languages and **translates them into English**. It extracts essential information from news articles, such

as headline, crop name, event type, date, location, severity, summary, and source link, ensuring that the ministry receives timely updates on relevant events published on the web.



About

- The Union Agriculture Ministry, in collaboration with the Wadhvani Institute for Artificial Intelligence (Wadhvani AI), developed Krishi 24/7.
- It is the first AI-powered solution for automated monitoring and analysis of agricultural news, powered by Google.org.

Working

- The tool scans news articles in multiple languages and translates them into English.
- It also addresses the need for an efficient mechanism in order to identify and manage agricultural news articles of interest to aid timely decision-making.

Features

- The tool extracts necessary information from news articles, such as headline, crop name, event type, date, location, severity, summary, and source link, ensuring that the ministry receives timely updates on relevant events published on the web.

Significances

- It will aid the Department of Agriculture and Farmers Welfare (DA&FW) in order to identify relevant news, generate timely alerts, and take prompt action to protect farmers' interests and promote sustainable agricultural growth through improved decision-making.

Krishi 24/7

IASEXAM.COM

<https://www.iaseexam.com/krishi/>

Krishi Jagran:

The Krishi Jagran app is designed to serve the agricultural community of India by providing timely and relevant information, resources, and services directly through a mobile platform. This app is an extension of the larger Krishi Jagran initiative, which includes a popular agriculture magazine published in multiple languages across India.

Conclusion

Digital journalism stands as a transformative force in the dissemination of news and information, adapting to and driving changes in the way society communicates and engages with the world. It increases the reach and influence of journalism by utilizing the power of the internet and digital technologies to provide real-time, interactive and multimedia-rich information. Despite facing challenges, many forms of journalism are used by innumerable organizations in order to address problems faced by the farming community and to provide solutions. Exploration and evolution of digital journalism is a testament to the adaptability and resilience in the field of agriculture.

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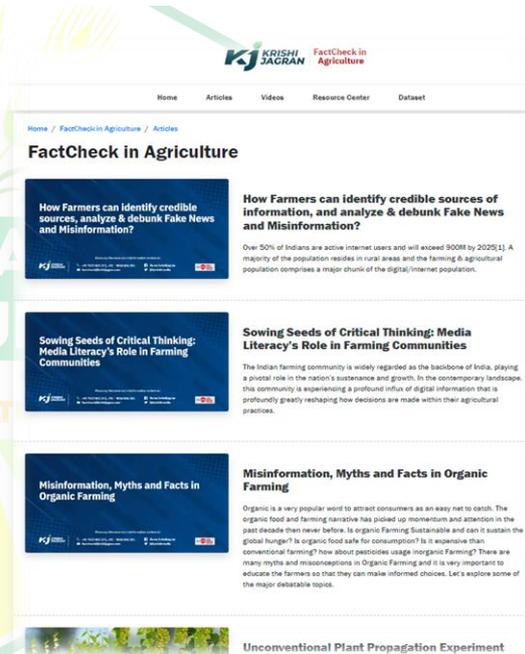
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KRISHI JAGRAN FactCheck in Agriculture

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FactCheck in Agriculture

How Farmers can identify credible sources, analyze & debunk Fake News and Misinformation?

Over 50% of Indians are active internet users and will exceed 900M by 2025(1). A majority of the population resides in rural areas and the farming & agricultural population comprises a major chunk of the digital/internet population.

Sowing Seeds of Critical Thinking: Media Literacy's Role in Farming Communities

The Indian farming community is widely regarded as the backbone of India, playing a pivotal role in the nation's sustenance and growth. In the contemporary landscape, this community is experiencing a profound influx of digital information that is profoundly greatly reshaping how decisions are made within their agricultural practices.

Misinformation, Myths and Facts in Organic Farming

Organic is a very popular word to attract consumers as an easy net to catch. The organic food and farming narrative has gained up momentum and attention in the past decade than never before. Is organic Farming Sustainable and can it sustain the global hunger? Is organic food safe for consumption? Is it expensive than conventional farming? How about pesticides usage inorganic Farming? There are many myths and misconceptions in Organic Farming and it is very important to educate the farmers so that they can make informed choices. Let's explore some of the major debatable topics.

Unconventional Plant Propagation Experiment

(Uttar Pradesh and Bihar) (B.P. & P. & P. & P.)

<https://krishijagran.com/>

Digital Agriculture: A New Dawn for Indian Farming



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Introduction

The world has always facing the biggest challenge in supplying food for the increasing population. Today, that challenge is sharper than ever. The global population has crossed 8 billion and is expected to reach nearly 10 billion by 2050. With two billion more mouths to feed, food demand will rise by almost 50 percent. For India, where agriculture sustains more than half of the population, this poses a critical question: how do we grow more food on shrinking farmland while also battling climate change, water shortages, and falling incomes?

The answer lies in digital agriculture, the fusion of farming with modern information technologies. From satellites to sensors, from drones to mobile apps, digital tools are redefining what it means to be a farmer. They promise not only higher yields but also lower risks, fairer prices, and a healthier planet.

Farming in India has always evolved with time. Traditionally, bullocks and wooden ploughs defined the earliest stage of agriculture. The Green Revolution brought machines, fertilizers, and pesticides, marking the next big leap. By the late 20th century, irrigation systems, automated machinery and scientific inputs shaped modern agriculture. Now, we stand at the threshold of smart farming powered by data and digital tools. The Internet of Things connects soil sensors and weather stations to farmers' phones. Artificial Intelligence predicts the right sowing time and detects plant diseases. Drones and robots reduce drudgery in spraying and harvesting. Big Data analytics turns countless pieces of information into useful advice for farmers. This journey reflects a shift from labor-intensive farming to knowledge-driven, precision-based agriculture.

Despite progress, farming is still a gamble for millions. A national survey across 18 states revealed some stark concerns. Natural calamities like floods and droughts remain the top worry. Low productivity and declining soil health affect incomes. Lack of irrigation facilities makes farmers dependent on uncertain monsoons. Market volatility and low crop prices leave farmers in debt, while labour shortages increase costs during peak seasons. For small and marginal farmers, who make up nearly 86 percent of India's farming population, these challenges are especially crushing.

Digital initiatives in Agriculture

Smart mobile apps are now leading the way. Kisan Suvidha App provides instant updates on weather, market prices, soil health, and government schemes. Plantix uses AI to identify plant diseases from a photo, guiding farmers on treatment. Iffco Kisan gives personalized crop advice and mandi prices in 10 languages. Bharat Agri acts as a one-stop platform for crop management, pest alerts, and farming tips.

Sensors in the soil are also making a difference. For example, Soilsens, a low-cost soil moisture sensor developed in India, has helped potato farmers in Gujarat save 22 percent water and boost yields by 20 percent. In Telangana, maize farmers recorded 10 percent higher output with sensor-based irrigation compared to traditional practices. Similarly, CultYvate, an agri-tech platform launched by entrepreneur Mallesh T., helps farmers monitor water use in crops like paddy. In some regions, farmers cut water usage by 40 percent while avoiding fungal diseases caused by over-irrigation.

Remote sensing and drones are revolutionizing the way fields are managed. Drones equipped with cameras and sensors can monitor crop health, map fields, and spray pesticides more efficiently. In Tamil Nadu, a paddy farmer who switched from manual spraying to drone spraying cut pesticide costs by almost half while also reducing labor needs. Artificial Intelligence is also changing farm decisions. The Sowing App, developed by

ICRISAT and Microsoft, analyzes weather forecasts, soil data, and crop models to tell farmers the best time to sow seeds. Piloted in Andhra Pradesh, it has already improved yields for groundnut farmers.

Government Support

The Indian government is steadily pushing digital tools into the hands of farmers. The Digital Agriculture Mission 2021–2025 promotes AI, blockchain, drones, and IoT. The National e-Governance Plan in Agriculture uses modern technologies for decision-making. The Sub-Mission on Agricultural Mechanization offers grants for drones to Krishi Vigyan Kendras and universities. The India Digital Ecosystem of Agriculture framework aims to create a unified platform for farmer data and services. Schemes like PM-Kisan and the Kisan Credit Card ensure financial security and easy access to loans. By integrating technology into policies, the government is ensuring that even small farmers are not left behind in the digital revolution.

Instances of Use

Real change is best seen in the lives of farmers. In Tamil Nadu, a paddy farmer with 10 acres reduced pesticide costs from Rs.11,000 to Rs.6,000 by using drones, while also saving labor. In Karnataka, precision farming trials showed that pigeon pea and paddy yields rose significantly under scientific nutrient and irrigation management. In Canada, dairy farmers who adopted automatic milking systems reduced milking time by more than half while maintaining milk quality, offering lessons for India's dairy sector. In Bangalore, poultry farms with automated houses increased egg production and improved bird health compared to conventional rearing. These examples prove that digital agriculture is not theory but is practice with tangible results.

Challenges

For India's millions of smallholders, certain measures are critical for success. Technology must be affordable and pay back within one cropping season. Devices should be portable and easy to install across small or shifting plots. Renting and sharing models through Custom Hiring Centres can make equipment like drones and harvesters accessible. Farmers also need training and awareness to make the most of new tools. At the same time, concerns about data privacy and the digital divide must be addressed so that no farmer is excluded.

Conclusion

Digital agriculture is more than a trend, it is a necessity. As climate change intensifies and food demand rises, technology offers a lifeline. By reducing waste, improving efficiency and connecting farmers directly to markets, digital tools ensure farming as both profitable and sustainable. But perhaps its biggest promise is empowerment. When a farmer can predict rainfall, diagnose a crop disease, or negotiate better prices, they gain confidence and dignity. This empowerment is as important as the yield itself.

The road ahead is not without hurdles like costs, connectivity gaps but also with resistance to change. Yet, the seeds of a digital revolution are already sprouting in India's fields. With the right support, digital agriculture can transform farming from a struggle for survival into a sustainable, thriving profession for the future. In short, digital agriculture is not just about gadgets, it is also about disseminating knowledge, power and hope to farmers.

Impact of Climate Change on Human Nutrition - Focus on Vitamin B12 and Vitamin-D



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Introduction:

Climate change is increasingly influencing human health, not only through extreme weather events and infectious diseases but also through its indirect effects on nutrition and micronutrient status, particularly vitamin D and vitamin B12. Vitamin D, a fat-soluble vitamin primarily synthesized in the skin upon exposure to ultraviolet B (UVB) radiation from sunlight, is especially vulnerable to climate-related changes. As global warming intensifies, we are witnessing more air pollution, urban smog, and reduced outdoor activity due to extreme heat, flooding, or poor air quality, all of which reduce sunlight exposure. This leads to decreased cutaneous production of vitamin D, increasing the risk of deficiency, particularly among urban populations, the elderly, people with darker skin, and children. Vitamin D deficiency has serious health consequences including bone demineralization (rickets and osteoporosis), weakened immune response, and an increased susceptibility to respiratory infections, which can be exacerbated during climate-driven disease outbreaks. These impacts are discussed in Understanding Nutrition and supported by clinical findings such as emphasizes the widespread nature and risks of vitamin D deficiency in modern environments.

Similarly, vitamin B12, a water-soluble vitamin essential for neurological function, red blood cell formation, and DNA synthesis, is indirectly affected by climate change due to its dependence on animal-based foods and soil microbes. B12 is produced by specific bacteria found in soil and in the guts of ruminant animals. Climate change threatens livestock systems through heat stress, water scarcity, and poor-quality forage, reducing the nutrient content of animal-derived foods like meat, milk, and eggs. At the same time, global advocacy for climate-friendly diets which are predominantly plant-based may inadvertently increase the prevalence of B12 deficiency, especially among populations who do not use fortified foods or supplements. Since B12 is not naturally present in plant foods, individuals following vegetarian or vegan diets without supplementation are at a greater risk of anemia, cognitive decline, and nerve damage. Furthermore, food insecurity and crop failure common outcomes of climate change may limit access to both vitamin-rich animal foods and fortified options, worsening deficiency rates in vulnerable regions.

Thus, both vitamins serve as critical markers of how climate change intersects with nutritional health, and their importance lies in the need for adaptive strategies such as public health policies promoting supplementation, food fortification, and sustainable yet nutrient-adequate diets. Monitoring and addressing vitamin D and B12 deficiencies will be essential for climate-resilient health systems in the future.

Understanding the Deficiencies

Vitamin B12 is a water-soluble vitamin crucial for red blood cell formation, neurological function, and DNA synthesis. Since it is naturally found in animal-based foods, vegetarians and vegans are more vulnerable to its deficiency.

Vitamin D, a fat-soluble vitamin, is essential for calcium absorption and bone health. It is primarily synthesized in the skin upon sun exposure, making it unique among vitamins. Dietary sources are relatively limited.

Trends in India

- **Vitamin B12 Deficiency:**
 - Studies indicate 50-70% prevalence in urban Indian adults.
 - High risk among vegetarians, pregnant women, elderly, and low-income groups.
- **Vitamin D Deficiency:**
 - Estimated to affect 70-90% of the Indian population.
 - Affects all age groups—children, adolescents, adults, and especially women.

- Reduced sun exposure due to indoor lifestyles, air pollution, and clothing habits.

Changes in Dietary Patterns:

Changes in dietary patterns influenced by climate change have significant implications for micronutrient intake, particularly for vitamins D and B12. Climate change affects food systems by altering agricultural productivity, biodiversity, and food availability, which in turn impacts the nutritional quality of diets. According to the FAO (2018) and IPCC Special Reports, global warming, shifts in rainfall, and extreme weather events are leading to reduced access to diverse and nutrient-rich foods. This shift has resulted in a growing reliance on plant-based, processed, and shelf-stable foods, especially in urban settings. While this may help in reducing greenhouse gas emissions, it also increases the risk of deficiencies in nutrients primarily found in animal-based products, such as vitamin B12.

Vitamin B12 is found almost exclusively in animal-derived foods—meat, dairy, and eggs. As climate-conscious dietary patterns push toward plant-based or vegetarian diets, populations are increasingly at risk for B12 deficiency, especially without proper supplementation. In *The American Journal of Clinical Nutrition* highlight that B12 deficiency can lead to megaloblastic anemia and irreversible neurological damage. Additionally, global livestock production may be affected by climate stress, which further threatens the availability of B12-rich foods.

Vitamin D, on the other hand, is unique in that it can be synthesized by the skin upon exposure to sunlight. However, changes in climate have influenced sun exposure patterns due to increased indoor lifestyles, urbanization, and atmospheric changes such as air pollution. These factors reduce the capacity for sufficient dermal synthesis of vitamin D. Moreover, dietary sources of vitamin D, like fatty fish, fortified dairy, and egg yolks, are becoming less accessible or consumed less frequently, especially among climate-conscious populations. Reduced sunlight exposure combined with limited dietary intake has contributed to widespread vitamin D deficiency, which is associated with bone disorders like rickets and osteoporosis, as well as impaired immune function.

Why deficiency occurs

Deficiencies in vitamin D and vitamin B12 are increasingly being linked to climate change through their effects on environmental exposure, agriculture, and dietary patterns. Vitamin D deficiency is mainly due to reduced skin synthesis caused by lower exposure to ultraviolet B (UVB) rays from sunlight. Climate change contributes to this reduction through increased air pollution, which blocks UVB radiation, as well as rising temperatures that encourage people to stay indoors or wear protective clothing. These behavioral adaptations limit sun exposure, particularly in urban areas.

Vitamin B12 deficiency, on the other hand, is closely linked to disruptions in food systems caused by climate change. B12 is found naturally only in animal-based foods, and climate-induced stress—such as drought, heatwaves, and altered rainfall—negatively affects livestock health, productivity, and the nutrient content of animal products. how climate variability threatens the stability of livestock-based food systems. Moreover, due to increasing environmental and ethical concerns, many populations are shifting toward plant-based diets, which are often low in B12 unless fortified.

Causative Factors:

Climate change contributes to vitamin B12 and vitamin D deficiencies through several interconnected causative factors related to environmental, agricultural, and behavioral changes. These micronutrients are vulnerable to climate-induced shifts in food production, dietary habits, and lifestyle patterns.

For vitamin B12, which is naturally found in animal-source foods such as meat, dairy, and eggs, climate change indirectly affects its availability through its impact on livestock systems. Rising temperatures, increased frequency of droughts, and reduced water resources stress animal agriculture, reducing productivity and increasing the cost of animal-derived products. This has led to a dietary transition in many regions toward more plant-based diets, either for economic reasons or environmental sustainability. While beneficial for lowering greenhouse gas emissions, this dietary trend reduces B12 intake since plants do not provide this vitamin. It emphasizes that populations following vegetarian or vegan diets without supplementation are at increased risk for B12 deficiency, leading to anemia and neurological impairments.

In the case of vitamin D, the major causative factor linked to climate change is the alteration in sunlight exposure. Vitamin D is synthesized in the skin upon exposure to UVB rays. However, increased air pollution, urbanization, and climate-driven changes in behavior such as staying indoors due to extreme heat or poor air quality have significantly reduced sun exposure. It explains that these environmental changes limit cutaneous production of vitamin D, contributing to widespread deficiency. Furthermore, climate impacts on marine ecosystems affect the availability of fatty fish, one of the few natural dietary sources of vitamin D. Ocean warming and acidification have been shown to reduce fish populations, limiting access to these nutrient-rich foods.

Strategies:

Climate change is altering the environmental and dietary landscape, which has significant implications for vitamin D and vitamin B12 status in populations. Vitamin D, primarily synthesized in the skin through sunlight exposure (specifically UVB radiation), is increasingly affected by changing climate patterns. Rising temperatures, increased air pollution, and changes in lifestyle due to urbanization (such as reduced outdoor activities and greater use of sun-protective clothing) are leading to decreased sun exposure, even in sunny regions. This contributes to widespread vitamin D deficiency.

On the other hand, vitamin B12 is obtained from animal-based foods, and its levels are influenced by changes in agricultural systems. Climate change negatively impacts livestock health, productivity, and the nutrient quality of animal products through heat stress, altered feed quality, and water scarcity. These changes threaten the availability and accessibility of B12-rich foods, especially in vulnerable populations. As reported in the Journal of the Science of Food and Agriculture climate-induced stress on food production systems may lead to micronutrient deficiencies including B12, especially in populations relying on subsistence agriculture. Additionally, shifts toward plant-based diets, partly motivated by climate concerns, may inadvertently increase B12 deficiency risks unless supplemented appropriately.

In terms of strategies, promoting safe sun exposure practices and considering vitamin D fortification of staple foods are key responses, as recommended by global health authorities. For B12, strategies include improving livestock health via climate-resilient practices, educating plant-based dieters on supplementation, and fortifying foods with B12 particularly in regions undergoing dietary shifts. Public health initiatives must integrate climate projections into nutrition planning, ensuring that future food and health systems are fortified against these emerging micronutrient challenges.

Effects:

Climate change has significant ill effects on vitamin D and vitamin B12 status, as documented in key nutrition and public health textbooks. For vitamin D, reduced sun exposure due to increased air pollution, extreme heat, and changes in lifestyle (e.g., staying indoors or covering skin outdoors) leads to widespread deficiencies. Limited UVB radiation due to environmental changes reduces cutaneous vitamin D synthesis, increasing risks of bone disorders like rickets and osteoporosis. Climate-related reductions in sunlight access, especially in urban and high-pollution areas, are a growing public health concern.

For vitamin B12, climate change disrupts livestock production through heat stress, water scarcity, and feed quality decline, lowering the availability of B12-rich foods. Plant-based dietary shifts, partly driven by climate concerns, also elevate deficiency risk without proper supplementation. B12 deficiency is linked to anemia, fatigue, and irreversible neurological damage, particularly in the elderly and vegans.

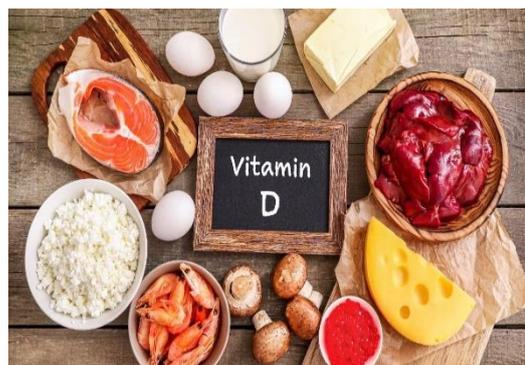
Food Sources to be incorporated in diet to reduce the effect of vitamin D and vitamin B12 deficiency:

Vitamin -D

- Fatty fish: Salmon, mackerel, sardines, tuna
- Fish liver oils: Cod liver oil (very rich)
- Egg yolks
- Beef liver
- Mushrooms exposed to UVB light (especially shiitake and portobello)

Fortified foods:

- Fortified milk and plant-based milk (soy, almond)
- Fortified margarine



- Fortified cereals
- Fortified orange juice

Vitamin B12 Food Sources:

Animal-based products:

- Meat: Liver (especially beef liver), beef, lamb
- Poultry: Chicken, turkey
- Fish and shellfish: Salmon, tuna, trout, clams (one of the highest)
- Dairy products: Milk, yogurt, cheese
- Eggs: Especially the yolk

Fortified foods for vegetarians/vegans:

- Fortified breakfast cereals
- Fortified nutritional yeast
- Plant-based milks



Conclusion:

Climate change significantly impacts human nutrition by contributing to deficiencies in vitamin D and vitamin B12 through environmental, agricultural, and behavioral changes. These deficiencies pose serious health risks including bone disorders, immune dysfunction, anemia, and neurological damage. Vitamin B12 and D deficiencies are silent epidemics affecting millions and impairing quality of life. With timely awareness, improved dietary practices, food fortification, and supplementation, these micronutrient gaps can be effectively bridged. A collaborative effort involving individuals, healthcare professionals, and policymakers is essential to combat this pressing nutritional concern.

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Advances in Hurdle Technology in Fish Preservation



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Abstract

Fresh fish is among the most perishable animal-based food products, largely due to its biochemical composition and high microbial load. To meet the increasing global demand for safe and high-quality seafood, research has emphasized the use of hurdle technology—the deliberate combination of multiple preservation factors that act synergistically to suppress microbial growth and extend shelf life. This article reviews current advancements in fish preservation through hurdle applications, including novel processing methods (high hydrostatic pressure, osmotic dehydration, pulsed light), packaging strategies (modified atmosphere, vacuum, active coatings), and the integration of predictive microbiology models. The physiological responses of microorganisms under stress—homeostasis disruption, metabolic exhaustion, and stress shock protein synthesis—are critically analyzed as underlying mechanisms. Case studies of preserved products, including fermented, refrigerated, and minimally processed fish, demonstrate the potential of combining hurdles to maintain nutritional and sensory quality. Future research must address knowledge transfer to industry, the optimization of active/smart packaging systems, and the integration of mathematical modelling for improved risk management and shelf life prediction.

1. Introduction

Global seafood consumption has steadily increased, rising from 9.9 kg per capita in the 1960s to nearly 20 kg in 2013, with projections indicating continued growth (FAO, 2016). However, fish remains an extremely perishable commodity, with spoilage primarily driven by microbial activity and biochemical reactions post-harvest. Traditional preservation methods such as freezing, salting, marinating, and canning have been widely applied but often compromise sensory and nutritional attributes.

Hurdle technology provides a modern approach by combining preservation factors at sub-lethal intensities, thereby reducing microbial viability while minimizing product deterioration. Instead of relying on a single severe treatment (e.g., heat), multiple mild hurdles—such as pH adjustment, water activity reduction, refrigeration, and natural antimicrobials—are layered to create environments that microorganisms cannot adapt to simultaneously (Leistner, 2000). This review synthesizes the state of the art in fish preservation hurdles, their mechanisms of action, applications in different product categories, and predictive modelling strategies.

2. Mechanisms of Antimicrobial Action in Hurdle Technology

2.1 Homeostasis Disruption

Microorganisms maintain tight internal control of pH and osmotic balance. Hurdle factors such as acidity, osmotic pressure, and low water activity destabilize this homeostasis. When multiple hurdles act concurrently, the energy required for repair overwhelms microbial cells, resulting in growth inhibition or death.

2.2 Metabolic Exhaustion

Energy depletion occurs when microorganisms attempt to repair stress-induced damage. For instance, bacterial spores surviving mild thermal treatments may fail to regrow under suboptimal water activity or pH conditions, leading to “autosterilization.”

2.3 Stress Shock Responses

Bacteria often produce stress proteins that confer cross-tolerance. However, simultaneous multi-target stresses complicate this adaptive mechanism, reducing microbial survival. This multitarget preservation is a key advantage of hurdle technology, ensuring microbial safety without resorting to harsh treatments.

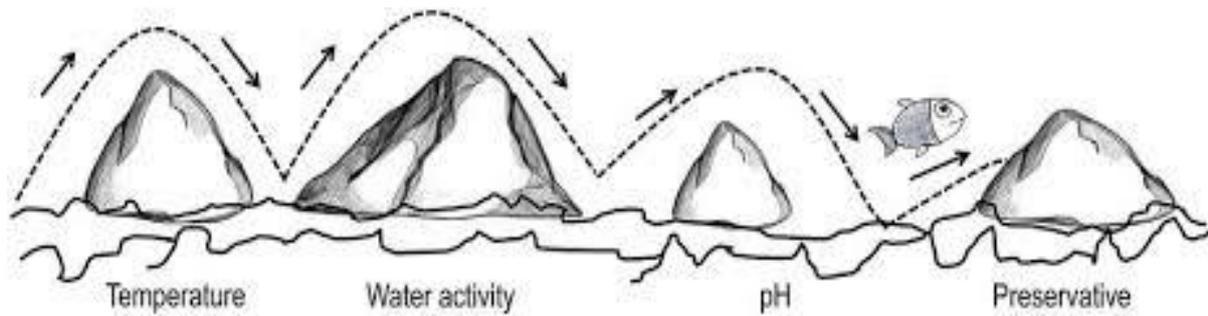


Figure 1: Hurdle effect in fish preservation

3. Applications of Hurdle Technology in Fish Products

3.1 Intermediate and High Moisture Products

Intermediate-moisture fish (a_w 0.6–0.9) relies on osmotic dehydration, solute addition, and preservatives to maintain microbial stability at ambient storage. High-moisture fish (>0.9 a_w), such as fresh fillets, require refrigeration but benefit from additional hurdles like modified atmosphere packaging (MAP) or incorporation of antimicrobials such as nisin or essential oils.

3.2 Fermented Fish Products

Fermentation introduces biopreservation by lactic acid bacteria, which generate organic acids, bacteriocins, and hydrogen peroxide. These natural hurdles reduce spoilage and pathogenic risks, while also enhancing flavor (e.g., umami development in fish sauce).

3.3 Thermally Treated Products

Moderate heat, combined with hurdles such as salt, sorbate, or edible coatings enriched with plant extracts, can extend shelf life while mitigating oxidative changes. High-pressure processing (HPP) integrated with mild smoking represents a promising alternative to intense thermal treatments.

3.4 Refrigerated Fish Products

Refrigeration alone is insufficient due to cold chain variability. Combined hurdles—MAP, vacuum packaging, natural extracts, and ozone treatment—enhance microbial safety and quality retention. Recent advances show that HPP with refrigeration can triple shelf life of Mediterranean fish species.

4. Predictive Modelling of Hurdle Effects

Quantitative microbial models are critical for designing effective hurdle combinations. Empirical and mechanistic models (e.g., Baranyi, logistic, Arrhenius-type, square root) have been applied to simulate growth of spoilage organisms (*Pseudomonas* spp., *Listeria monocytogenes*) and formation of biogenic amines such as histamine in tuna.

Examples include:

- ❖ Arrhenius-type models for evaluating *Pseudomonas* growth in osmotically dehydrated seabream (Tsironi & Taoukis, 2014).
- ❖ Baranyi models for assessing microbial inhibition under MAP and nisin treatments.
- ❖ Stochastic models for predicting halibut spoilage under variable acid and salt concentrations.
- ❖ These predictive tools provide a framework for shelf life determination, risk management, and HACCP integration.

Conclusion

Hurdle technology represents a holistic preservation approach that balances microbial safety, sensory quality, and nutritional integrity of fish products. By combining mild treatments, it avoids the trade-offs of traditional preservation, reduces energy costs, and supports consumer demand for minimally processed foods.

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LIQUID NANO-CLAY AND THE TRANSFORMATION OF UNPRODUCTIVE SANDY SOILS - PROMISE FOR INDIA



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Introduction

Sandy soils, common in Rajasthan's Thar, the Kutch region of Gujarat, coastal belts, and many inland riverine and post-mining sites, are often low in water and nutrient retention, making agriculture marginal or impossible without heavy irrigation and inputs. A Norwegian innovation called Liquid Nano-Clay (LNC) aims to change that by converting clay into a liquid suspension that coats each sand grain; the treated sand behaves more like a loam, holding water and nutrients far better and enabling plant growth where none existed before.

What is LNC, and how does it work?

LNC is a mechanically processed clay dispersed in water (nanometric clay suspension) and produced via a patented mixing process. When sprayed onto sandy soils using regular irrigation equipment, the nanoclay particles coat sand grains and bind minerals and organic matter into a porous, sponge-like matrix that retains moisture. This increases the surface area, raises water and nutrient retention, and can allow root establishment quickly (the company reports deep penetration and rapid changes within hours to days). Trials and project reports have noted penetration to depths of approximately 60 cm and large improvements in water holding capacity and nutrient retention.

Evidence and real-world trials

This technology was developed by Desert Control AS (Norway) and has been showcased in trials and demonstration projects (including trials in the UAE and projects promoted through EU research channels). Several independent articles and project portals have reported that LNC can drastically reduce the amount of clay needed compared with traditional mechanical mixing, and that previously unusable sands were made productive in short timeframes. Masdar City and other Middle Eastern initiatives have specified the LNC for green infrastructure and landscape projects.

1) UAE (Farms, Turf & Trees)

Independent and customer pilots in the UAE reported 35-50% irrigation water savings on vegetables, turf grasses, and palms, and several sites observed 17-62% yield gains and lower salinity in treated zones (Figure 1). A frequently cited operational note is "sand to soil in ~7 hours," meaning that the land can be planted the same day.

2) Masdar City (Urban Landscaping)

Masdar City credits the LNC with significant water conservation while maintaining green public spaces (Figure 2). City statements highlight multi-month tracking and large irrigation reductions in landscape trees and turf.

3) Academic/Technical validation

Recent peer-reviewed and technical papers describe LNC's soil-physics basis of LNC and water-retention improvements in sandy substrates, aligning with field outcomes reported in UAE pilot (Figure 3).



Figure 1. LNC in UAE (Source: <https://impact.desertcontrol.com/uae-farming>)



Figure 2 . LNC in Masdar city (Source: <https://desertcontrol.com/impact-initiatives/>)



Figure 3 . LNC in UAE pilot (Source : <https://desertcontrol.com/impact-initiatives/>)

4) Programmatic Endorsements

The UN World Food Programme's Innovation platform profiles LNC for cutting water use (up to ~50%) and boosting yields and documents pilot work in arid zones (Figure 4).



Figure 4 . LNC practiced in very light sands (Source: <https://desertcontrol.com/impact-initiatives/>)

Together, these lines of evidence point to a consistent pattern: less water in, more plant performance out, especially on very light sands.

Why this matters for India?

India has millions of hectares of sandy and degraded soils with large social and economic costs. Thar Desert (Rajasthan), large tracts of shifting dunes and low-productivity land. Kutch (Gujarat) and parts of Saurashtra saline sandy soils, coastal dunes and reclaimed land. Coastal sands (Tamil Nadu, Andhra, Odisha, Kerala) and riverine sandy patches (parts of Karnataka, Madhya Pradesh, Bihar). Post-mining spoil and construction sand are local areas where soil restoration would enable greening or agricultural activities. If LNC can be shown to work under Indian environmental and crop contexts, it could enable fodder production, agroforestry (drought-tolerant trees and shrubs), horticulture (orchards/fruit in irrigated plots), millet/pulse cultivation, dune stabilization, and urban landscaping with far less water usage.

How LNC would be applied in India?

1. Application method:

LNC is mixed on-site (clay + water + patented mixing) and applied using conventional irrigation equipment, such as sprinklers, water wagons, pivot systems, or drip redistribution systems. This makes it compatible with existing farm machinery in larger irrigation projects or contractor services for smallholders. The reported penetration depths are up to ~60 cm.

2. Target use cases (short-term pilots):

Irrigated demonstration plots near borewells/GP irrigation schemes (to test fodder and millet/pulse crops). Peri-urban landscaping and green belts (city greening projects in arid towns). Afforestation/windbreaks with drought-resistant species (prosopis alternatives, native species). Post-mining and reclaimed land where topsoil is absent. Saline coastal margins, but only after salinity interaction tests.

3. Crop and system choices

Start with low-input, short-duration crops and fodder (e.g., bajra/millet, cowpea, cluster bean, sorghum, and forage sorghums) and fast-growing tree species for soil stabilization. If the results are positive, move to higher-value horticulture in irrigated plots.

4. Sourcing clay and logistics

LNC uses natural clay as a feedstock. For India, sourcing sustainable clay (local deposits) will be critical, as the transport of large volumes raises costs. Urban/regional clay suppliers or partnered brick/ceramic industries could be sources, but the sustainability and biodiversity impacts of clay extraction must be assessed.

5. Water and irrigation efficiency

LNC is claimed to reduce irrigation needs due to improved retention, which is a major advantage in water-scarce India; however, water savings should be measured in pilots.

Practical considerations

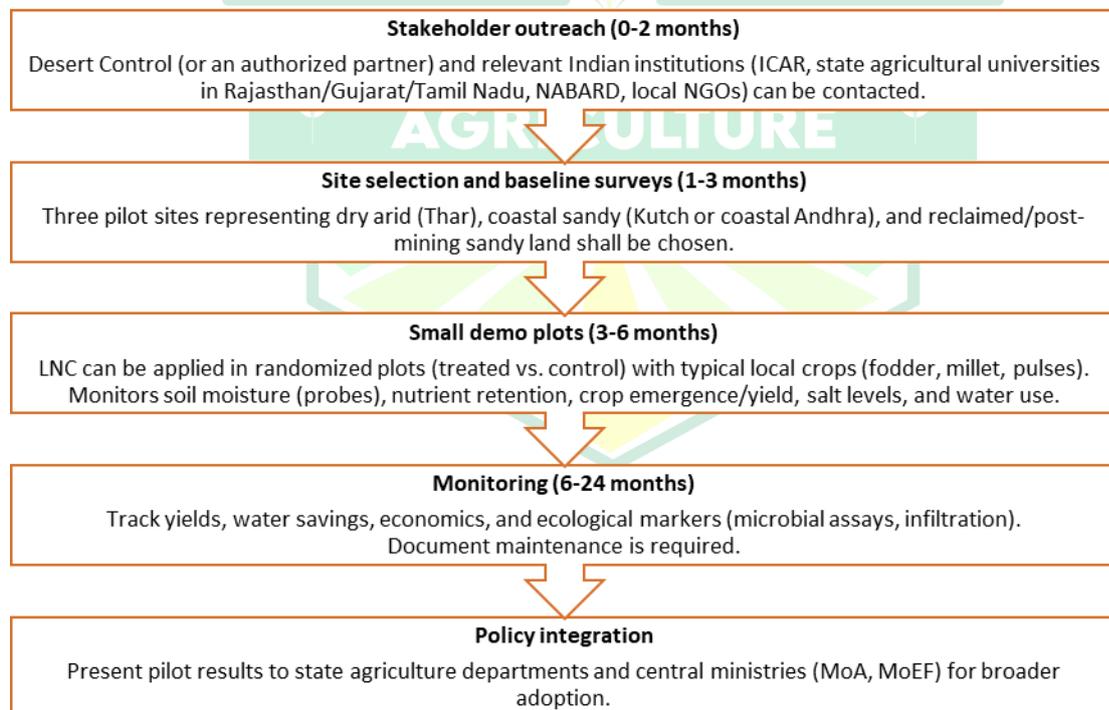


Figure 5. Suggested Pilot Roadmap for India (Source: Author's Compilation, 2025)

Limitations, risks, and research requirements

Although LNC is promising, it is not a turnkey panacea. Key issues to be investigated include:

- Long-term soil ecology impacts on native soil microbes, mycorrhizal associations, and carbon cycling require monitoring. Some reports have emphasized that LNC can enable beneficial fungi, but independent long-term studies are limited.

- Coastal and saline sands may react differently to salinity. LNC may hold salts as well as water; therefore, careful trials and regular EC monitoring are needed.
- The environmental cost of clay mining must be factored into life cycle assessments.
- While the technology claims to require much less clay than mechanical mixing, deploying it at scale requires localized production/mixing units, transport logistics, and financing models for smallholders.
- Soil amendments sometimes require approvals (state agricultural departments, environmental clearances), especially for large-scale landscape projects or when groundwater recharge is affected.

Benefits of LNC and financing (high-level)



Figure 6. Benefits of LNC (Source: Author's Compilation, 2025)

The main costs are clay sourcing and on-site mixing units, application (equipment/fuel), and monitoring. The potential benefits include higher yields, lower irrigation, and increased land value. Smallholder adoption will likely require subsidies or contractor-based service offerings initially. Detailed local costing must follow the pilot data.

Conclusion

Liquid NanoClay is one of the most widely reported innovations aimed at turning desert and sandy soils into productive land. For India, it is a promising technology worth rigorous, locally designed pilots, ideally run by partnerships between Desert Control (or local licensees), ICAR/state agri universities, and state governments (Rajasthan, Gujarat, Andhra/Tamil Nadu). Trials should prioritize water-scarce, high-social-impact areas (fodder production, marginal farmer livelihoods) and include ecological monitoring to ensure long-term sustainability.

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Move Better, Heal Faster: The *Cissus Quadrangularis* Secret



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Abstract

The plant is rich in bioactive compounds such as triterpenoids, flavonoids, stilbenes, and ascorbic acid, which contribute to its therapeutic potential. In terms of agronomy, *C. quadrangularis* grows well in tropical and subtropical areas, showing excellent resistance to drought, low input needs, and soil-adaptability. It is appropriate for both home gardens and commercial agriculture since it is simple to propagate via stem cuttings. *C. quadrangularis* has enormous promise as a multipurpose crop for cultivation, with prospective uses in the functional food, herbal medicine, and nutraceuticals industries due to its broad pharmacological relevance, nutritional value, and durability under stress.

Introduction

Commonly referred to as Hadjod, Bone Setter, or Veldt Grape, *Cissus quadrangularis* is a perennial, succulent vine belonging to the vitaceae family of grapes. It is indigenous to India and portions of Africa and Southeast Asia, and its therapeutic qualities have been utilized for ages in traditional medicine, especially in Ayurveda and Siddha. It is a potential crop for cultivation and commercialization due to its great medicinal value, easy maintenance and adaptability to various agroclimatic zones.

Applications

Because of its high calcium, carotene, and phytosterol content, the plant is most well-known for its ability to aid in bone mending. It is used to treat joint-related conditions, fractures, and osteoporosis. It also has gastroprotective, anti-inflammatory, antioxidant, and anti-diabetic qualities. Supplements containing its stem extracts are claimed to help people lose weight and build muscle. In certain cultures, it is occasionally eaten as a vegetable in addition to its medical purposes (Hamid *et al.*, 2023).

Cultivation potential

Cissus quadrangularis is perfect for growing in arid and semi-arid areas since it can withstand drought and grows well in tropical and subtropical temperatures. Its low input requirements and ability to be propagated by stem cuttings lower manufacturing costs. Growing this plant might benefit small and marginal farmers financially because to the growing demand for herbal and nutraceutical goods (Aushma *et al.*, 2021).

Adaptation to different environment

It is indigenous to Africa, Java, Malaysia, Sri Lanka, and India, and it is found throughout the tropical and subtropical zones. Locals utilize the plant as a therapeutic herb. It is well known that *C. quadrangularis* can withstand drought stress. It's interesting to note that this plant's stems and leaves react differently to dryness. During the rainy season, the leaves only emerge on fresh stems, and during drought, they are abscised. It has a characteristic of arid savanna in which only succulent stems remain throughout the dry season (Qingyun *et al.*, 2024).

Prospects for the Market

The market for nutraceuticals and herbal medicines is expanding gradually worldwide, and *Cissus quadrangularis* has established a name for itself in the sports nutrition and bone-health sectors (Charoensup *et al.*, 2024). It is sold by well-known manufacturers of herbal and Ayurvedic products and comes in a variety of forms, including capsules, powders, and liquids. Its commercial prospects are expected to be enhanced by consumers' growing demand for sustainable health products and natural cures (Patel, 2021 & Singh, 2012).



Conclusion

Cissus quadrangularis has a lot of potential as a commercial crop and as a therapeutic plant. It can be a profitable item in the herbal market and a viable option for farmers due to its shown health advantages and climate-adaptability. Its value chain can be further improved by methodical cultivation and quality control.

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QTL-seq: A Genomic Shortcut to Unlock Trait Architecture



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Abstract

Unravelling the genetic basis of complex traits is crucial for crop improvement but conventional QTL mapping is often time-consuming and less efficient in detecting minor-effect loci. QTL-seq, developed by Takagi *et al.* (2013), integrates bulked segregant analysis with whole-genome resequencing for rapid and precise identification of QTLs. This approach involves sequencing DNA bulks from individuals at trait extremes, calculating SNP and Δ SNP indices, and pinpointing candidate genomic regions through statistical analysis. Unlike traditional marker-based methods, QTL-seq eliminates the need for prior marker development and allows genome-wide detection of SNPs, InDels, and structural variants. Its high resolution and efficiency make it especially powerful for dissecting complex agronomic traits in diverse species. QTL-seq thus serves as a valuable genomic shortcut, accelerating marker-assisted breeding and functional genomics.

Introduction

Unravelling the genetic basis of complex agronomic traits has long been a bottleneck in crop improvement. Identifying and isolating QTLs plays a crucial role in enhancing crop improvement through marker-assisted selection (MAS) and in uncovering the genetic mechanisms that control important traits. However, conventional QTL mapping is often laborious and time-intensive, as it involves generating segregating populations and developing DNA markers for linkage analysis. Moreover, traditional QTL mapping exhibits reduced sensitivity for detecting minor-effect QTLs and is predominantly applicable to diploid species, with limited utility in allopolyploid species due to their complex genomic architecture and inheritance patterns. To address these limitations, Takagi *et al.*, (2013) developed and applied QTL-seq, a next-generation sequencing-based bulk segregant analysis approach, for rapid and high-resolution identification of QTLs associated with blast resistance in rice.

QTL-seq is an advanced approach that integrates bulked segregant analysis (BSA) with whole-genome resequencing to rapidly pinpoint genomic regions responsible for trait variation between two parental lines in a segregating population. Unlike conventional QTL mapping methods that rely on predefined molecular markers such as SSRs, RFLPs, or INDELS, QTL-seq eliminates the need for prior marker development by leveraging genome-wide sequence data. This allows for the comprehensive identification of diverse genetic variations, including SNPs, insertions/deletions, and structural variants across the entire genome, providing a valuable reservoir of markers for accelerating marker-assisted breeding.

Methodology for QTL-seq

The QTL-seq approach starts with the creation of a segregating population, such as F_2 or recombinant inbred lines (RILs), followed by accurate phenotypic evaluation. Individuals exhibiting the most extreme expressions of the trait are selected and grouped into high and low bulks. DNA from each group is then extracted, pooled, and subjected to whole-genome sequencing. By analyzing differences in allele frequencies between these contrasting bulks, researchers can rapidly identify genomic regions linked to the trait of interest. A step-by-step overview of the QTL-seq method is provided below (Figure 1).

Step I: Development of Segregating Population

The initial step in QTL-seq involves the development of a suitable mapping population by crossing two parental lines that exhibit contrasting phenotypes for the trait of interest. Depending on the trait being studied, various types of segregating populations can be employed. Common choices include F_2 populations, recombinant inbred lines (RILs), and doubled haploids (DHs). RILs and DHs are particularly advantageous due to their high levels of homozygosity. Since individuals within each line are genetically uniform, they serve as effective proxies for

clonal replicates, allowing repeated phenotypic evaluations. This makes them especially useful for detecting QTLs with small effects, as the replication increases statistical power and reliability.

Step II: Phenotyping

After establishing the mapping population, individuals are evaluated for the target trait to determine the segregation pattern. When the trait is influenced by multiple quantitative trait loci (QTLs), the distribution of phenotypic values generally follows a normal curve, indicating the involvement of several genes with additive effects. From this population, individuals that exhibit the most extreme phenotypes (highest and lowest) are selected.

Step III: DNA extraction, Bulking and Sequencing

Genomic DNA was extracted from 20-50 individuals at each phenotypic extreme using 100 mg of fresh leaf tissue per plant. Equal amounts of DNA were pooled to create two bulks: one representing the high phenotype and the other the low. Each bulk underwent whole-genome resequencing with a coverage depth above 6×. While most genomic regions display balanced allele frequencies (~1:1), regions linked to trait-specific QTLs show biased allele representation, indicating association with the trait. Sequencing libraries were prepared from 5 µg of DNA and sequenced using 76 cycles on the Illumina Genome Analyzer IIX. Reads with >10% bases having a Phred score below 30 were excluded from downstream analysis.

Step IV: Read Alignment and SNP Detection

To pinpoint the regions of the genome linked to the trait, the DNA sequences from both groups those with high and low trait values are to be aligned with a known reference genome using a tool called BWA. After alignment, look for small changes in the DNA sequence, known as SNPs, that are different from the reference genome (short reads-k). These differences helped highlight the specific parts of the genome that might be influencing the trait.

Step V: SNP index calculation

The proportion of k in the total short reads (n) covering a particular genomic position ($= kn^{-1}$) is defined as the SNP index. It quantifies the proportion of sequencing reads containing the alternative allele at a specific SNP position within a DNA pool (bulk). The SNP index is 0 if the entire short read contains genomic fragments from the parent that was used as a reference sequence. The SNP index is 1 if all the short reads represent the genome from the other parent. An SNP index of 0.5 means an equal contribution of both parents' genomes to the bulked progeny.

Step VI: ΔSNP index calculation

Comparing the SNP-index plots of both DNA bulks is crucial for accurately identifying true QTLs and distinguishing them from genomic regions showing segregation distortion due to unrelated factors like meiotic drive. Such distortions can cause similar shifts in SNP-index values in both bulks, potentially masking genuine trait-associated loci. To better detect candidate QTL regions, the SNP-index values from the 'High' and 'Low' bulks are compared by calculating their difference, known as the Δ(SNP-index). This is done by subtracting the SNP index of the 'Low' bulk from that of the 'High' bulk:

$$\Delta\text{SNP-index} = \text{SNP-index (High bulk)} - \text{SNP-index (Low bulk)}$$

A ΔSNP-index significantly different from zero indicates a trait-associated region, with positive values showing allele enrichment in the trait-expressing bulk and negative values indicating enrichment in the non-trait bulk.

Step VII: Visualization and QTL Identification

To clearly observe patterns in the ΔSNP-index, smoothing techniques such as sliding window averaging are applied. Statistical thresholds or confidence intervals, often determined through simulations or permutation tests are then used to identify genomic regions significantly associated with the trait. The region showing the highest absolute ΔSNP-index value is considered the most likely to contain the candidate gene(s).

Step VIII: Marker Development and Validation

Molecular markers closely linked to the identified QTL region, such as SNPs, InDels, or SSRs are developed for further use. These markers are then validated by genotyping both the original mapping population and independent populations. Their association with the target trait is confirmed through linkage analysis or additional QTL mapping studies.

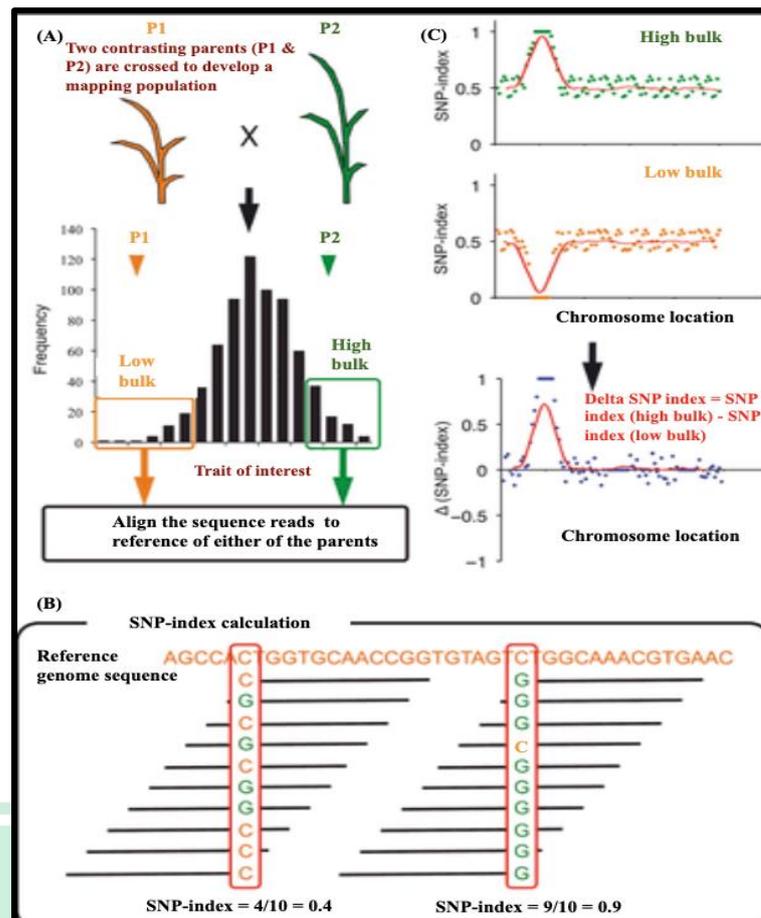


Figure 1. Overview of QTL-seq methodology

Advantages of QTL-seq

QTL-seq offers a rapid and efficient approach for identifying genomic regions associated with specific traits, significantly outperforming traditional QTL mapping in terms of speed. By leveraging whole-genome sequencing data, QTL-seq directly detects SNPs, InDels, and structural variants across the entire genome, eliminating the need for pre-designed markers. This method is particularly effective for dissecting complex traits governed by multiple QTLs, especially when coupled with extreme phenotype selection. Its versatility allows application across a broad range of traits in both plants and animals, provided a reference genome is available, and it delivers high-resolution insights into genetic variation.

Conclusion:

In conclusion, QTL-seq represents a powerful and efficient genomic strategy for dissecting the genetic architecture of complex traits. By integrating bulked segregant analysis with whole-genome resequencing, it enables rapid, high-resolution identification of trait-associated loci without the need for prior marker development. Its ability to detect a wide range of genetic variants across the genome makes it a versatile tool applicable across diverse species and traits, significantly accelerating the pace of marker-assisted breeding and functional genomics.

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Bacterial Quorum Sensing and Its Role in Fish and Shellfish Pathogenesis



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Abstract

Quorum sensing (QS) is a bacterial communication system that regulates gene expression through the production and detection of signalling molecules. In aquaculture, QS plays an important role in coordinating virulence, biofilm development, and host colonization among several pathogenic bacteria. Gram-negative bacteria such as *Vibrio harveyi*, *Vibrio parahaemolyticus*, and *Aeromonas hydrophila*, as well as Gram-positive bacteria like *Edwardsiella tarda*, rely on QS to modulate infection processes. By synchronizing activities that enhance survival and pathogenicity in high-density aquatic environments, QS contributes significantly to the onset and persistence of bacterial diseases. This article discusses the mechanisms of QS in aquatic bacteria, highlights its impact on disease outbreaks in fish and shellfish, and explores its potential as a target for developing innovative control measures to safeguard aquaculture production.

Keywords: Quorum sensing, aquatic pathogens, autoinducer, AHL, virulence, biofilm

Introduction

Infectious bacterial diseases are of significant threat to modern aquaculture operations because pathogens can easily multiply in high-density fish farm culture systems. Hence, proper control of these bacterial diseases leads to successful aquaculture operations. Although the use of antibiotics has been the standard practice for the treatment of bacterial diseases, widespread applications have raised increasing concerns regarding antimicrobial resistance in fish pathogens and environmental pollution by antibiotic residues. Vaccines serve as alternatives but its application is limited in aquaculture due to diversity of pathogens and challenges to immunize fish larvae. This has generated an urgent need for complementary disease management mechanisms. Quorum sensing (QS) is a bacterial communication mechanism that regulates important pathogenic processes like the production of virulence factors, the formation of biofilms and other traits, it offers a particularly promising target for intervention (Bruhn et al., 2005).

Quorum sensing

Quorum sensing (QS) is a complex system of intercellular communication by which bacteria synthesize, detect, and respond to extracellular chemical signals called autoinducers (AIs). The fundamental knowledge of QS came from research that showed how acyl-homoserine lactones (AHLs) control bioluminescence in *Vibrio fischeri*. AI concentrations in the surrounding environment increase in proportion to the growth of bacterial populations. Bacteria regularly track this information to check for any changes in cell counts and modifies gene expression. QS direct activities that benefit bacterial communities by controlling genes. Formation of biofilm, spores, bioluminescence, secretion of virulence factors, competence, and production of antibiotics are among the QS-controlled processes (Santos et al., 2021).

Basic principles of quorum sensing

All QS systems function in accordance with three basic principles, despite the differences in their underlying molecular processes and regulatory elements. Initially, the members of the bacterial community produce autoinducers, which spread throughout the environment and stay below the detection threshold when bacterial populations are at low cell density (LCD). On the other hand, at high cell density (HCD) - bacteria produce enough cumulative autoinducer levels that can be detectable and cause cellular reactions. Additionally, these autoinducers are recognized by specific receptor proteins that are embedded in cellular membranes or in the cytoplasm. Finally, autoinducer detection not only stimulates the expression of genes required for coordinated behaviours of bacterial community but also enhances further autoinducer synthesis, creating a positive feedback mechanism that likely ensures population-wide coordination (Rutherford and Bassler, 2012).

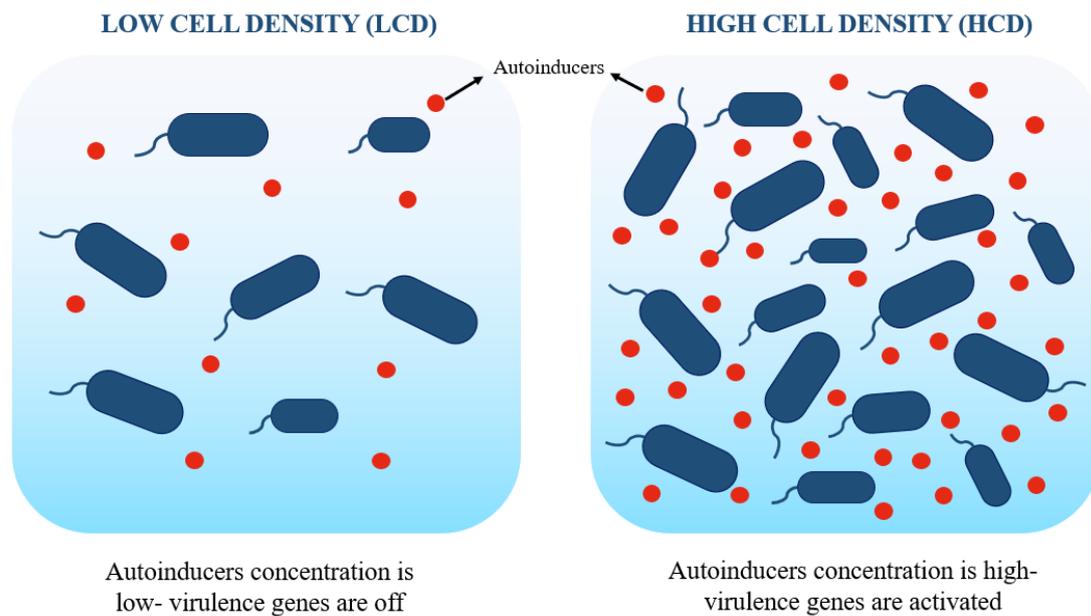


Fig 1: Quorum sensing in bacteria

Mechanism of QS in Gram-positive vs Gram-negative bacteria

Different kinds of QS systems are used by Gram-positive and negative bacteria. Gram-positive bacteria have thick peptidoglycan layer and they use autoinducing peptides (AIPs) as signalling molecules. These peptides are processed and released from the cell. At HCD, AIP binds to membrane bound receptor like histidine kinase. This results in autophosphorylation of the receptors, kinase activity is increased. Within the QS network, the phosphorylated regulator subsequently promotes target gene transcription. AIPs again return into cytoplasm of Gram-positive bacteria. These AIPs together with transcription factors alter patterns of gene expression and related activities. Gram-negative bacteria use tiny molecules as autoinducers (AI) to communicate. These are either AHLs or other compounds that require S-adenosyl methionine (SAM) to be produced. The cell produces AIs, which freely permeate both the outer and inner cellular membranes. At HCD, AIs bind to transcription factors in the cytoplasmic receptors. The QS regulon's gene expression is controlled by the AI-bound receptors. Two-component histidine kinase receptors that work similarly to those in Gram-positive bacteria (Rutherford and Bassler, 2012).

Role of Quorum Sensing (QS) in Aquatic Pathogens

Quorum sensing (QS) is a central regulatory mechanism in many aquatic pathogens, affecting fish and shellfish. These bacteria use QS to control the expression of virulence factors, biofilm formation, and colonization - all of which are critical for establishing infections in aquaculture systems.

Vibrio harveyi is a pathogen in shrimp hatcheries and marine fish farms, and it uses a complex QS system involving multiple signaling molecules (AHLs and autoinducers). QS controls bioluminescence, extracellular protease production, and biofilm development, all of which enhance its pathogenic potential (Henke & Bassler, 2004).

QS system of *Vibrio parahaemolyticus* is similar to that of *V. harveyi*. *V. parahaemolyticus* produces several autoinducers. QS regulates toxin production, contributing to acute hepatopancreatic necrosis disease (AHPND), a major cause of shrimp mortality.

Aeromonas hydrophila causes motile aeromonad septicaemia (MAS), a devastating bacterial disease in freshwater aquaculture. Its QS system regulates the production of haemolysins, cytotoxins, and proteases. These virulence factors are expressed in synchrony at high bacterial densities, helping *A. hydrophila* evade host defences and cause systemic infections (Swift et al., 1999).

Edwardsiella tarda pathogen of catfish, rely on QS to regulate virulence and persistence. AHL-based QS systems in these bacteria control secretion systems, virulence genes, and invasion factors, enabling successful colonization of the fish gut and internal organs (Zhou et al., 2019).

Conclusion

Quorum sensing serves as a fundamental determinant of virulence regulation in aquaculture pathogens, enabling them to adapt, communicate, and collectively establish infections in hosts. Its role in modulating biofilm formation, secretion of toxins, and evasion of host defenses underscores its importance in the pathobiology of *Vibrio*, *Aeromonas*, and *Edwardsiella*. Recognizing QS as a central driver of disease progression provides new opportunities for intervention. Targeting QS pathways rather than killing bacteria offers a sustainable, resistance-avoiding approach to disease management in aquaculture. Future advances in understanding QS diversity and signalling networks will be helpful in designing effective quorum quenching strategies that can reduce pathogen impact and support healthier aquaculture systems.

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Resource-Conserving Tillage Machineries in Agriculture



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Introduction

The continuous deterioration of natural resources and climate change has put enormous challenges before growers and researchers to further improve the crop productivity to meet the food grains demand of the burgeoning population. The faster depletion of groundwater, soil health deterioration, and change in rainfall patterns are key issues being faced in every agroecological zone of the country. Such problems are more prominent in dryland agriculture due to the limited moisture regime during the crop growth period. The delay in the field operation, seeding at improper depth, mismanagement of crop residue, and inadequate water-conserving techniques lead to poor germination, resulting in lesser yield and profitability. Under the favorable moisture regime, a shift from conventional tillage to resource conserving tillage practices, viz. zero and strip tillage either on flat or broad bed, would be helpful to reduce the fuel cost, operational time, and associated harmful air pollutants along with increased net profit for farmers. The use of such resource conserving technologies along with crop residue as mulch and subsurface drip irrigation system will provide the double benefits of energy and water conservation.

1. Laser Land Leveler

Laser land leveling is a modern technology that significantly conserves irrigation water by precisely leveling agricultural fields (Figure: 1). Traditional leveling methods often result in uneven fields with high and low areas, leading to water stress and surplus conditions, which can cause inconsistent crop growth and yields. Laser land leveling addresses this by using equipment like scrapers, hydraulic systems, transmitters, receivers, and control boxes to level fields accurately within ± 2 cm of mean elevation.



Figure 1: Laser land leveler in field

1.1 Benefits

This process improves water distribution, productivity, and crop yield, while reducing water, nutrient, and energy inputs. Laser land leveling can increase crop yields and net income significantly, such as a 5 q ha⁻¹ increase in rice yield and a 23.2 % increase in winter wheat yield. Overall, this technology helps farmers reduce costs and improve profitability amidst climate challenges (Chen *et al.*, 2022).

Table. 1 List of laser land levelers machines in India

Sl. No.	Make	Model
1	Fieldking	FKLLLEF-7
2	Mahindra Agribusiness	Dharti Mitra Laser Leveller
3	Sonalika Agro Solutions	Sonalika Laser Leveler
4	Swaraj	Swaraj Laser Leveler
5	Bull Agro	Bull Laser Land Leveler

2. Chisel Plough

In arid and semiarid regions, periodic rainfall followed by long dry spells creates a hard, impervious soil layer. The chisel plough, a common tool with curved bars, is used to break this subsurface hardpan, facilitating water infiltration without inverting the soil, which helps preserve crop residue on the surface and reduces erosion

(Figure: 2). It can perform deep ploughing up to 45–75 cm, improving root development and drought tolerance by enhancing soil structure.

2.1 Benefits

Chisel ploughing enhances soil moisture and crop yield, benefiting root and tuber crops. Studies show significant improvements in soil penetration resistance, root length density, water use efficiency and grain yield when using chisel ploughs. Additionally, this method can lead to better nitrogen uptake, increased grain yield and reduced nitrogen losses and emissions compared to conventional ploughing (Mohanty et al., 2007).



Figure 2: Chisel plough operation in Field

Table. 2 List of Chisel plough machines in India

Sl. No.	Make	Model
1	John Deere	CP20 Series
2	Dasmesh	Dasmesh 661 Chisel Plough
3	Sonalika Agro Solutions	Sonalika CP-9, CP-11
4	Shaktiman	Shaktiman CH Series
5	Landforce	Landforce CP-5, CP-7

3. Subsoiler

A subsoiler is a heavy tillage implement (Figure: 3) used to break compacted soil layers at depths of 60–90 cm, often caused by repeated use of heavy machinery or constant-depth plowing. It is heavier than a chisel plough and requires a high-power tractor (>60 hp) due to its high draft requirements. A 20° lift angle on the tool face helps reduce draft by leveraging upward shear force. Curved shanks on subsoilers also require less draft force than straight ones.

3.1 Benefits

Subsoiling has been shown to improve soil water storage and crop yields in dryland agriculture. For instance, a 14.7–19.7% increase in maize yields with intermittent subsoiling. Similarly, observed a 23.5–29.1% increase in grain yield and improved water use efficiency for spring maize with subsoiling. In rainfed agriculture, conservation or minimum tillage is recommended to enhance soil water storage (Liu et al., 2016).

Table. 3 List of subsoiler machines in India

Sl. No.	Make	Model
1	Agristar	Agristar Subsoiler, Agristar Deep Subsoiler
2	Farmking	Farmking Subsoiler, Farmking Deep Tillage Subsoiler
3	Swan Agro	Swan Agro Subsoiler
4	Garud	Garud Rigid Subsoiler
5	Fieldking	Fieldking Rigid Subsoiler



Figure 3: Subsoiler operation in Field

4. Mulcher

A tractor-operated implement known as a PTO (power take-off) mulcher is used for shredding and chopping crop residue (Figure: 4). Power is transmitted from the PTO shaft to the gearbox and then to the crushing drum through

a V-belt drive. The high-speed rotating blades, which can be ‘Y’-shaped or hammer types, cut crop residue into small pieces.

4.1 Benefits

This process aids in faster decomposition and facilitates direct seeding with a spatial seed drill, conserving soil moisture and improving soil health. This operation supports the benefits of direct seeding under residue-covered fields (Verma *et al.*, 2016 & Kumar *et al.*, 2018).



Figure 4: Mulching operation in paddy field

Table. 4 List of mulcher machines in India

Sl. No.	Make	Model
1	Maschio	Maschio Gaspardo Mulcher
2	Fieldking	FKMM 125
3	Shaktiman	SRM 180
4	Mahindra	MM 130
5	Sonalika	SLX 150

Conclusion

Resource-conserving technologies for tillage operations significantly enhance agricultural sustainability by improving soil health, reducing fuel consumption, and lowering operational costs. These technologies, including reduced tillage and mulching, promote efficient use of resources and minimize soil erosion. By facilitating residue management and moisture conservation, they support higher crop yields and profitability. Adoption of these practices also contributes to environmental conservation and resilience against climate change. Overall, these technologies play a crucial role in advancing sustainable agriculture.

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Tissue Culture and Micropropagation in Pomegranate: Ensuring Quality Planting Material



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Abstract:

Pomegranate (*Punica granatum* L.) is a highly valued fruit crop, both nutritionally and economically, with India being the largest producer and exporter. However, expanding its commercial cultivation is limited by the unavailability of high-quality, disease-free, and genetically uniform planting material. Conventional propagation methods such as stem cuttings and air layering are often slow, season-dependent, and susceptible to disease transmission. To overcome these limitations, tissue culture and micropropagation have emerged as powerful biotechnological tools that allow rapid, large-scale production of elite plants. This article explores how these methods are transforming pomegranate cultivation by ensuring consistency, improving disease resistance, and supporting the long-term sustainability of orchards.

Key words: Agri Innovation, Micropropagation, Next-Gen Horticulture, Pomegranate

Introduction:

Pomegranate (*Punica granatum* L.), known for its rich nutritional content and vibrant ruby-red arils, plays a crucial role in India's horticultural sector. It not only supports the livelihoods of thousands of farmers but also contributes significantly to the country's export earnings. Major producing states like Maharashtra, Gujarat, and Karnataka are witnessing a surge in demand for premium cultivars such as 'Bhagwa' and 'Super Bhagwa'. However, this growth is hindered by the lack of consistent, disease-free planting material. Traditional propagation methods like stem cuttings and air layering often result in variable plant quality and increased susceptibility to diseases like bacterial blight. To overcome these limitations, tissue culture and micropropagation have emerged as promising biotechnological tools. These techniques enable the rapid, large-scale production of genetically uniform and pathogen-free plants in a controlled environment. As demand for high-quality fruits rises, tissue culture holds the potential to revolutionize pomegranate cultivation and ensure sustainable production.

Understanding Tissue Culture and Micropropagation:

Tissue culture refers to the cultivation of plant cells, tissues, or organs in a sterile environment on a nutrient medium. When used for mass multiplication, it is called **micropropagation**.

The process begins with a tiny portion of the plant—called an **explant**—usually taken from shoot tips, nodal segments, or meristems. This explant is cleaned, placed in a sterile culture medium with essential nutrients and hormones, and grown under controlled conditions. Over time, it develops into multiple shoots, which are later rooted and hardened before being transferred to the field.

What makes this technique revolutionary is its ability to:

- Produce **true-to-type** (genetically identical) plants
- Multiply elite cultivars **rapidly and in large numbers**
- Ensure **year-round propagation**, irrespective of seasons
- Eliminate diseases and pests from planting stock

These advantages are especially critical for crops like pomegranate, where uniformity, fruit quality, and disease resistance directly influence market value.

Why Pomegranate Needs Tissue Culture:

While pomegranate is a hardy, drought-tolerant crop, it is increasingly vulnerable to a range of biotic and abiotic stresses.

1. Disease Pressure

One of the most serious threats is **bacterial blight**, caused by *Xanthomonas axonopodis* pv. *punicae*. It spreads rapidly and severely affects productivity and fruit quality. Traditional propagation methods often unknowingly

transfer this disease to new orchards. Tissue culture provides a solution by enabling the **production of pathogen-free plants**, verified through regular screening and molecular tools.

2. Clonal Uniformity

Elite cultivars like 'Bhagwa', 'Super Bhagwa', 'Mridula', and 'Arakta' are in high demand for their yield, taste, and export potential. However, **variability in conventional cuttings** can lead to inconsistent field performance. Tissue culture ensures **clonal fidelity**, meaning all propagated plants are genetically identical to the mother plant.

3. Rapid Expansion Needs

With rising exports and new orchards being established across states like Gujarat, Rajasthan, and Madhya Pradesh, there's a surge in demand for quality saplings. Tissue culture can fulfil this demand with unmatched speed and efficiency.

Step-by-Step: The Micropropagation Protocol in Pomegranate:

The standard protocol involves five stages:

1. Explant Collection and Sterilization

Young, actively growing shoots from disease-free mother plants are collected. They are then surface-sterilized using solutions like sodium hypochlorite or mercuric chloride to eliminate surface contaminants.

2. Culture Initiation

The sterilized explants are inoculated onto Murashige and Skoog (MS) basal medium supplemented with growth regulators such as BAP (6-Benzylaminopurine) or kinetin for shoot induction.

3. Shoot Multiplication

Once shoots emerge, they are sub cultured repeatedly to produce multiple shoots. Cytokinin promote shoot proliferation, and repeated subculturing leads to a high multiplication rate—often **20–30 shoots per cycle**.

4. Rooting

Individual shoots are transferred to a medium enriched with auxins like IBA (Indole-3-butyric acid) to stimulate root formation.

5. Hardening and Acclimatization

Rooted plantlets are gradually acclimatized in a greenhouse environment to reduce transplant shock. After 4–6 weeks, they are ready for field planting.

(According to **Chavan et al. (2022)**, micro propagated plants of cv. 'Bhagwa' showed **100% clonal fidelity and superior field performance**, including higher fruit yield and disease resistance.)

Commercial Success Stories and Adoption:

India is home to numerous tissue culture labs and companies that have adopted and refined this technique for pomegranate. Some key players include:

- **Jain Irrigation Systems Ltd.**
- **Grow more Biotech Ltd.**
- **Agri Biotech Tissue Culture Lab**
- **Rasi Seeds Pvt. Ltd.**

These companies have developed commercial micropropagation protocols for elite cultivars and supply thousands of plants annually to farmers, particularly in Maharashtra and Gujarat.

Moreover, **ICAR-National Research Centre on Pomegranate (NRC), Solapur**, and **Junagadh Agricultural University (JAU)** have played pioneering roles in developing tissue culture protocols and validating field performance of micropropagated plants.

Farmers who adopted tissue culture plants report:

- Higher fruit set and uniform ripening

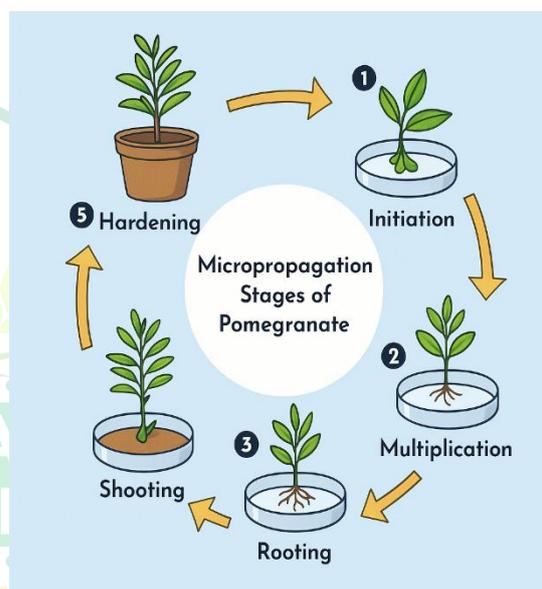


Figure 1: Stages of Micropropagation

- Earlier bearing
- Better market price due to uniform size and colour
- Improved resistance to bacterial blight and wilt

Challenges in Scaling Tissue Culture in Pomegranate:

Despite the proven benefits, large-scale adoption faces certain challenges:

• High Initial Investment

Setting up and running a tissue culture lab involves significant capital expenditure—ranging from ₹25 lakh to over ₹1 crore.

• Technical Expertise

The process requires skilled staff trained in sterile techniques, media preparation, and plant physiology.

• Genotype-Specific Protocols

Some pomegranate cultivars respond poorly to standard protocols, necessitating **variety-specific optimization**.

• Acclimatization Losses

Improper hardening can lead to high mortality when plantlets are transferred from lab to field.

• Quality Assurance

Substandard labs may sell Somaclonal variants or diseased plants. This calls for **strict certification and regulation**, such as those proposed by **DBT's NCS-TCP (National Certification System for Tissue Culture Raised Plants)**.

Government Support and Policy Interventions:

To boost adoption, the Government of India supports tissue culture under various schemes:

- **Rashtriya Krishi Vikas Yojana (RKVY)** – Provides financial support to biotech startups and nurseries.
- **Mission for Integrated Development of Horticulture (MIDH)** – Offers subsidies for tissue culture infrastructure.
- **PM Formalization of Micro Food Processing Enterprises (PMFME)** – Encourages small-scale propagation units with technical and financial assistance.

State horticulture departments also offer **training programs** and **buyback arrangements** for certified labs to encourage farmer adoption.

Sustainability and Climate Resilience:

In the context of **climate change**, tissue culture plays a vital role in:

- **Accelerating the spread of climate-resilient cultivars**
- **Minimizing pesticide use** by reducing disease incidence
- **Improving productivity per unit area**, thereby reducing land pressure

By combining this with other sustainable practices like **drip irrigation, integrated nutrient management, and IPM (Integrated Pest Management)**, farmers can transition to **climate-smart horticulture**.

Conclusion: The Future is Tissue-Cultured:

As India seeks to become a global leader in fruit exports, ensuring **reliable, quality planting material** becomes the cornerstone of success. Tissue culture and micropropagation, with their ability to revolutionize pomegranate production, represent a leap forward from traditional farming methods. To fully realize their potential, we need a collaborative approach—linking research institutions, private labs, government policy, and farmer awareness. When science, scalability, and sustainability come together, pomegranate cultivation can not only thrive but flourish. By investing in biotech today, we are not just growing plants—we are cultivating prosperity, resilience, and a fruitful future.

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Wellness – Focused Ornamental Pot Gardening



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Introduction

Plants and their components have been used as ethno-medicine for centuries by indigenous societies throughout to cure various ailments. Ayurveda and Unani systems of medicine have extensively documented numerous plants for therapeutic properties the Rig Veda written between 4500 to 1600 BC, is regarded as the earliest source of traditional knowledge on plant medicine.

Beyond their therapeutic capabilities many plants have amazing aesthetic value making them ideal for bringing a touch of elegance into landscapes or homes and also allows people to create a harmonious balance between nature and beauty. In this article, we tried to gather the information related to ornamental pot plants that have medicinal value too.

Aloe vera \ Ghrithkumari \ Burn plant

Scientific name: *Aloe barbadensis*

Family: Liliaceae

Part used: Leaves



Aloe vera is a low-maintenance succulent that thrives in dry and desert-like conditions which makes it ideal for both indoor and outdoor environments. It has thick and spiky leaves which aid in its aesthetic appeal and occasionally produced yellow or orange flowers, further enhance its ornamental value. Aloe vera gel is widely used to treat burns, wounds, skin issues, and even internal ailments like liver problems and intestinal worms. It's commonly found in cosmetic products and easily propagated through suckers.

Lemon grass

Scientific name: *Cymbopogon flexuosus*

Family: Poaceae

Part used: Leaves and stem

Lemon grass is characterized by its aromatic, citrus-scented foliage and a lush, fountain-like growth pattern. This low maintenance plant flourishes well with plenty of sunlight, making it an excellent choice for balconies. It is used as a stimulant, carminative, antiperiodic, perfumery, hair oil, herbal tea, aroma and soap. It is propagated through slips which ensure an easy cultivation for both new and experienced gardeners.



Brahmi \ Herb of Grace \ Jalnaveri \ Babies tear

Scientific name: *Bacopa monnieri*

Family: Plantaginaceae

Part used: Whole plant

Brahmi has delicate leaves with white or blue flowers. Its natural creeping growth makes it perfect for hanging baskets or for draping elegantly over the edges of pots which creates a beautiful cascading effect in container arrangements. Brahmi prefers well-drained soil and moderate sunlight with water-logged conditions. In addition to its aesthetic qualities, Brahmi is recognized for its medicinal properties especially in boosting cognitive

function. Leaves are believed to improve the receptive and retentive capacity of mind. Propagation is done by cuttings during summer or rainy season.



Periwinkle \ Sadabahar

Scientific name: *Catharanthus roseus*

Family: Apocynaceae

Part used: Roots, flower and leaves

Periwinkle is a versatile ornamental plant with glossy foliage and bright flowers which adds charm to balconies and compact areas with partial shade. The plant is propagated by seeds or vegetatively through cuttings. It grows in tropical as well as subtropical areas but growth is better in tropical regions. With its year-round foliage and ongoing blooms it offers consistent visual appeal in hanging baskets, window boxes, or decorative containers. Roots of periwinkle contain alkaloids like ajmalicine and reserpine which have hypotensive and antiplasmatic properties. Leaves contain vincristine and vinblastine used in cancer therapy.



Pathar khar \ Pathar chatta \ Life plant \ Miracle leaf

Scientific name: *Bryophyllum pinnatum*

Family: Crassulaceae

Part used: Leaves and stem

Pathar Khar commonly known as "miracle leaf," recognized for its distinctive scalloped leaves and the capacity to produce plantlets along the edges which is used in propagation. It's eye-catching bell-shaped flowers available in red, yellow, or pink further boost its ornamental value. It is a favored succulent well suited to indoor and requires minimal watering. Green fleshy leaves helps to treat respiratory issues like bronchitis, asthma, relieves kidney stone and urinary problem.



Akarkara

Scientific name: *Splenthes acmella*

Family: Asteraceae

Part used: Leaves and flower



It is a beautiful perennial herb with spreading growth habit and commonly referred to as "Mount Atlas" daisy. The striking yellow flowers with red undersides and fern-like leaves creates a visual display. This plant prefers full sunlight making it a low-maintenance option for terrace, balconies or rock gardens. Plant is used to treat urinary system trouble, dental like toothache and gum issues. Its leaves is used to prepare a curry called "Akarkara ka sag" which is beneficial for urinary health. Mostly cultivated in august.

Ashwagandha \ Asgandh \ Winter cherry \ Punir

Scientific name: *Withania somnifera*

Family: Solanaceae

Part used: Dried roots and leaves

Ashwagandha has attractive yellow or green color flower with delicate foliage. Its bushy growth and evergreen nature contributes in enhancing its ornamental value. The semi-tropical areas receiving low rainfall are suitable for cultivation of this crop. The crop requires dry season during its growing period. Ashwagandha is a multipurpose medicinal herb that is used to treat emaciation, weakness, inflammation, blood sugar regulation, weight reduction, and male impotence. It contains antibacterial, anti-inflammatory and antioxidant qualities and is used as a general tonic to combat stress while boosting overall health and well-being.



Sarpgandha / Chota chand / Serpentina root

Scientific name: *Rauvolfia serpentina L.*

Family: Apocynaceae

Part used: Roots



It is an evergreen shrub having attractive white and pink flowers. Its unique foliage, delicate blooms and adaptability to potted conditions makes it a valuable in adorning the gardens. It thrives best in loam and sandy loam soil with partial shade, it is ideal for indoor and outdoor pots. Propagated through root cutting, root stumps, stem cutting and seeds. Roots are used to treat hypertension, insomnia, anxiety, epilepsy and snake bite.

Fennel

Scientific name: *Foeniculum vulgare*

Family: Apiaceae

Part used: Seeds

Annual plant which has delicate and fern like yellow foliage. It grows upright, creating a striking feature in pots. Its ability to attract the pollinators like butterflies, magnify the overall garden ecosystem. Thrives best in cold weather with lots of sunshine. Can be propagated through seeds. It is a culinary herb with anise like flavour use to aid digestion, relieves gas, bloating and improve lactation.



Mint \ Pudina

Scientific name: *Mentha spp.*

Family: Lamiaceae

Part used: Leaves



It has attractive and highly fragrant green leaves. Due to its upright growth and refreshing scent it is suitable for kitchen gardens, balconies and hanging baskets. Requires cool/temperate climate. Can be propagated through suckers or stolons. It is a calming herb used to treat digestive problems, nausea, headaches, respiratory issues, skin irritation and promotes fresh breath and oral health. It is known to provide cooling sensation which aids against gastric problems.

Tulsi \ Holy basil

Scientific name: *Ocimum sanctum*

Family: Lamiaceae

Part used: leaves, seeds

Attractive fragrant leaves with purple or white flowers. Tulsi act as a air purifier and brings positivity to the environment. It enhances the serenity of the area. It can't withstand in waterlogged condition requires well-drained soil. Propagated through seeds. Use to treat various health issues like cold, cough, asthma, diabetes and earache, and its oil is used in dental care, perfumery, and cosmetics due to its antibacterial and insecticidal properties.



Lavender

Scientific name: *Lavendula angustifolia*

Family: Lamiaceae

Part used: Leaves, stems and flowers

Vibrant purple flower with attractive green leaves. Its fragrant flowers and leaves adds a calming aroma to any space and also provides a serene ambience. It is resistance to frost and drought. Propagated through seeds and cuttings. Lavender essential oil has numerous benefits, including combating halitosis, antiseptic properties, relieving spasms and anxiety, and promoting digestion and urine production due to its key components like linalyl acetate and linalool.



Rosemary

Scientific name: *Rosmarinus officinalis*

Family: Lamiaceae

Part used: Leaves and flower

Rosemary is a popular potted ornamental plant recognized for it's needle-like evergreen leaves and stunning blue, purple, or white flowers. The plant's fresh pine-like aroma enhances both indoor and outdoor environments. Its adaptability to container gardening makes it ideal for sensory gardens, mixed displays and as a stylish kitchen accent. Optimum temperature for growth is below 30°C in frost-free tropical and subtropical regions with summer monsoon. Can be propagated through root cuttings. Helps to treat digestive issues like heartburn, gas, bloating and abdominal pain. Can also help boost memory and reduce inflammation. Rosemary oil can be applied to the scalp to increase volume of hair.



Ajwain \ Carrom seed

Scientific name: *Trachyspermum ammi*

Family: Apiaceae

Part used: Seeds or leaves

Ajwain has beautiful white blooms with thick, bushy and aromatic green leaves that contribute both aesthetic and culinary value making it an excellent choice for ornamental kitchen gardens and kitchen windows. It is a cold loving crop as a rabi season crop, it is sown in the months of September and October in northern plains. Whereas, for kharif season



crop it is sown from July to August. Can be propagated through seeds. Treats digestive issue like acidity, soothes respiratory problems and reduce inflammation.

Geranium \ Rose scented geranium

Scientific name: *Pelargonium graveolens*

Family: Geraniaceae

Part used: Leaves, roots and flowers

Geranium is an ideal pot plant with a variety of shades in red, pink, white and orange that provide beauty and diversity to indoor and outdoor environments. Can be grown in temperate, subtropical and tropical climates but thrives best in sub-tropical climate. Temperatures below 3°C will kill the plant. It can be propagated through stem cuttings. Geranium oil is used to treat various health issues such as diabetes, dysentery, liver problem and urinary stone.



Conclusion:

Plants such as aloe vera, lemon grass, brahmi, tulsi, mint, and others have a unique combination of medicinal and aesthetic benefits, which makes them perfect for ornamental container gardening. These plants not only give several health advantages but they also enhance the beauty of landscapes and houses. By introducing such plants into our living spaces, we may achieve a healthy balance of nature and beauty, benefiting both physical and emotional health.



Polymerase Chain Reaction (PCR) and Beyond: Modern Methods for Shrimp Pathogen Detection



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Abstract

Shrimp aquaculture has emerged as one of the fastest-growing food production sectors worldwide, yet it remains vulnerable to devastating diseases caused by viruses, bacteria, and parasites. Rapid and accurate pathogen detection has become the cornerstone of effective disease management. Among molecular techniques, **Polymerase Chain Reaction (PCR)** has revolutionized shrimp health diagnostics by enabling highly sensitive and specific identification of pathogens such as White Spot Syndrome Virus (WSSV), Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV), and Enterocytozoon hepatopenaei (EHP). However, modern aquaculture now demands faster, more robust, and field-adaptable methods that extend beyond PCR. Advances such as quantitative real-time PCR (qPCR), loop-mediated isothermal amplification (LAMP), CRISPR-based diagnostics, and next-generation sequencing (NGS) offer new horizons for shrimp pathogen detection. This article reviews the evolution of PCR in shrimp health management, highlights modern diagnostic technologies, and discusses future perspectives in integrating molecular biology with bioinformatics and digital aquaculture systems for sustainable shrimp farming.

Keywords - Shrimp aquaculture, Polymerase Chain Reaction (PCR), Pathogen detection, qPCR, LAMP, CRISPR diagnostics, Next-generation sequencing (NGS).

Introduction

Shrimp aquaculture is a vital contributor to global food security and international trade, particularly in countries such as India, Vietnam, Thailand, and Ecuador. Yet, the industry faces recurrent losses due to **disease outbreaks**, which can wipe out entire crops within days. Viral pathogens like **White Spot Syndrome Virus (WSSV)** and **Taura Syndrome Virus (TSV)**, bacterial infections like **Vibrio parahaemolyticus** (causing Acute Hepatopancreatic Necrosis Disease, AHPND), and microsporidians such as **Enterocytozoon hepatopenaei (EHP)** remain major threats.

Traditional diagnostic methods such as histopathology and immunological assays provided early insights but were often slow and lacked sensitivity. The advent of **molecular diagnostics**, particularly **Polymerase Chain Reaction (PCR)**, transformed shrimp health management by enabling early, accurate, and reliable detection of pathogens even before visible symptoms emerged.

The Rise of PCR in Shrimp Pathogen Detection

What is PCR?

PCR, developed by Kary Mullis in 1983, is a molecular technique that amplifies specific DNA sequences, allowing scientists to detect the presence of pathogens in minimal sample quantities. Its sensitivity, specificity, and reproducibility made it a game-changer for aquatic animal health diagnostics.

Application in Shrimp Aquaculture

- **White Spot Syndrome Virus (WSSV)**: One of the first shrimp pathogens detected using PCR, enabling early interventions.

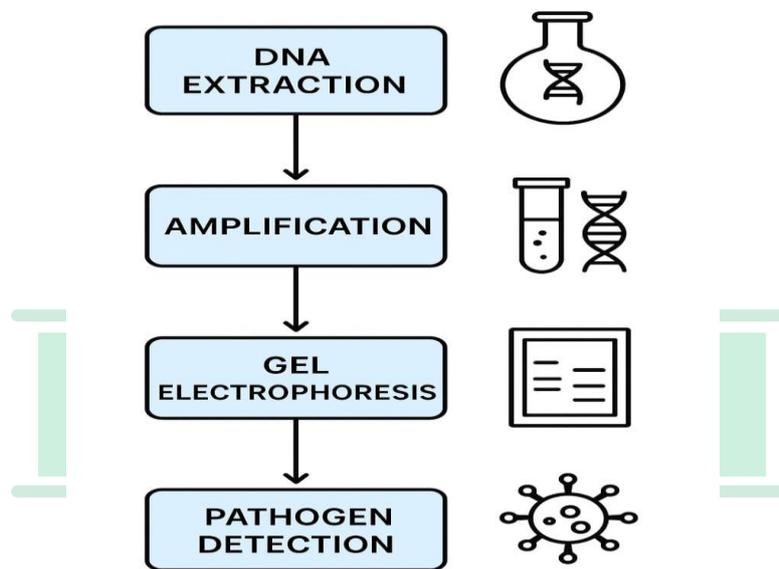
- **Infectious Hypodermal and Hematopoietic Necrosis Virus (IHHNV):** Routine PCR screening helped in breeding virus-free stocks.
- **Yellow Head Virus (YHV):** PCR allowed differentiation between virulent and avirulent strains.
- **Microsporidians (EHP):** PCR confirmed the presence of this parasite in hepatopancreatic tissues, supporting disease management.

Advantages of PCR

- High sensitivity and specificity.
- Early pathogen detection (even in asymptomatic shrimp).
- Standardization for routine diagnostic laboratories.

Limitations

- Requires sophisticated laboratory infrastructure.
- Skilled personnel are needed for accurate interpretation.
- Time-consuming sample preparation and thermal cycling.



Picture : Flowchart showing PCR steps

Advanced PCR-Based Technologies

Quantitative PCR (qPCR/Real-Time PCR)

qPCR measures DNA amplification in real-time using fluorescent markers, offering both detection and quantification of pathogen load.

- Application: Monitoring viral loads of WSSV for risk assessment.
- Advantage: Helps differentiate between low-level infections and acute outbreaks.

Multiplex PCR

Allows detection of multiple pathogens in a single reaction.

- Example: Simultaneous screening for WSSV, IHHNV, and EHP.
- Advantage: Saves time and resources in routine diagnostics.

Nested PCR

Uses two sets of primers in successive reactions to enhance sensitivity.

- Application: Detecting low concentrations of pathogens in broodstock.

Reverse Transcriptase PCR (RT-PCR)

Used for RNA viruses such as YHV and TSV.

- Converts RNA to cDNA before amplification.

PCR TECHNIQUES IN SHRIMP PATHOGEN DETECTION

	PCR	qPCR	RT-PCR	MULTIPLEX PCR
SENSITIVITY	+++	++	++	++
SPECIFICITY	+++	++	++	+++
COST	LOW	HIGH	HIGH	LOW
SPEED	FAST	MODERATE	FAST	FAST

+ → Low sensitivity

++ → Moderate

+++ → High sensitivity

Picture : Comparison chart of PCR, qPCR, RT-PCR, and Multiplex PCR in shrimp pathogen detection.

Beyond PCR: Emerging Modern Methods

While PCR remains a gold standard, aquaculture requires **faster, cheaper, and field-deployable tools**. Modern advancements are bridging these gaps.

1. Loop-Mediated Isothermal Amplification (LAMP)

- Amplifies DNA at a constant temperature without thermal cyclers.
- Provides results in less than an hour, visible through turbidity or color change.
- Portable and suitable for on-farm diagnostics.
- Example: LAMP assays developed for **WSSV, TSV, and Vibrio spp.**

2. Recombinase Polymerase Amplification (RPA)

- Isothermal amplification method operating at low temperatures (37–42°C).
- Rapid (15–30 minutes) and suitable for field settings.
- Works with lateral flow strips for visual detection.

3. CRISPR-Based Diagnostics

- Uses CRISPR-Cas systems for sequence-specific recognition.
- Platforms such as **SHERLOCK** and **DETECTR** show promise in pathogen detection.
- Potential for **ultra-sensitive detection** of emerging shrimp pathogens.

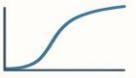
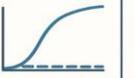
4. Next-Generation Sequencing (NGS)

- Provides comprehensive insights into the **shrimp microbiome** and pathogen diversity.
- Useful in identifying **novel or unknown pathogens**.
- Application: Discovery of EHP and new Vibrio strains.
- Limitation: High cost and complex data analysis.

5. Biosensors and Nanotechnology-Based Diagnostics

- Portable biosensors integrating nanomaterials can detect pathogens in real-time.
- Example: Gold nanoparticle-based sensors for WSSV detection.

COMPARISON CHART

PCR	qPCR	RT-PCR	Multiplex PCR
			
			
PATHOGEN	PATHOGEN	PATHOGEN	PATHOGEN
DETECTION	DETECTION	DETECTION	DETECTION

Integration of Molecular Diagnostics with Shrimp Health Management Farm-Level Applications

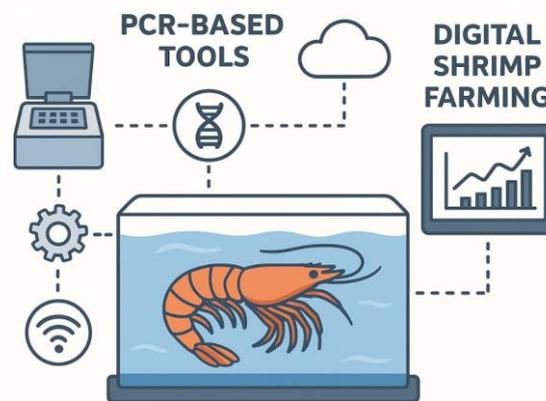
- **Routine Screening:** PCR and LAMP for broodstock certification.
- **Early Warning Systems:** qPCR quantification to monitor pathogen load.
- **Biosecurity:** Preventing pathogen introduction into hatcheries and ponds.

Policy and Trade Implications

- **International Trade Compliance:** PCR certification required for shrimp export.
- **Disease Surveillance Programs:** National authorities rely on molecular diagnostics to track outbreaks.

Digital Integration

- Combining molecular data with **Artificial Intelligence (AI)** and **Internet of Things (IoT)** for predictive disease modelling.
- Mobile diagnostic kits linked with cloud databases for real-time reporting.



Picture: Diagram showing integration of PCR-based tools with digital shrimp farming systems.

Future Perspectives

- **Point-of-Care Diagnostics:** Development of **smartphone-based detection kits** for farmers.
- **CRISPR-LAMP Hybrids:** Combining technologies for speed and ultra-sensitivity.
- **Low-Cost Sequencing Platforms:** Democratizing NGS for widespread aquaculture use.
- **One Health Approach:** Integrating shrimp pathogen monitoring with global aquatic health surveillance.

The evolution of diagnostics from PCR to cutting-edge molecular tools reflects the industry's commitment to sustainable and disease-resilient aquaculture.

Conclusion

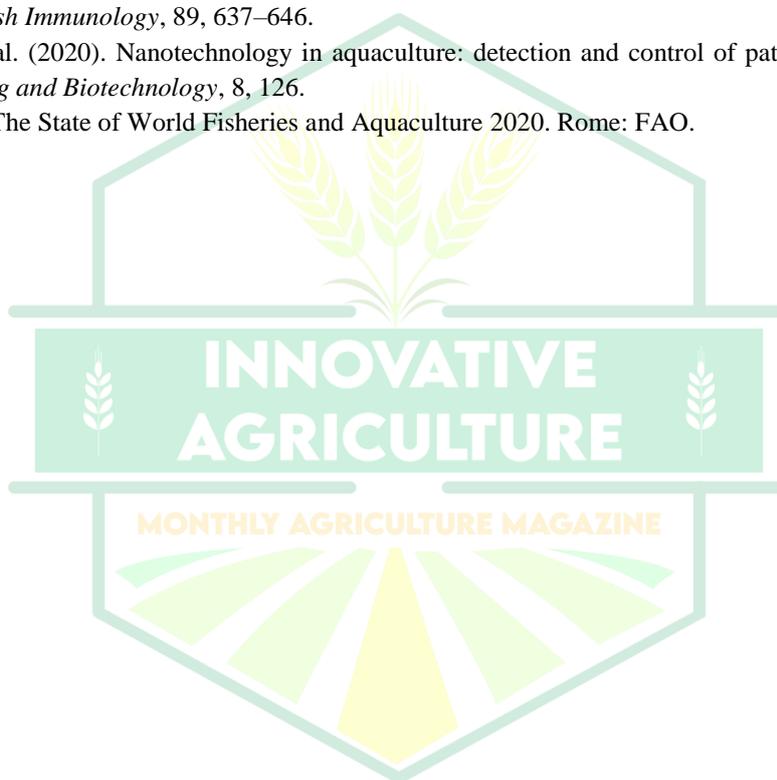
The journey of shrimp pathogen detection has been marked by **scientific breakthroughs** that transformed disease management in aquaculture. PCR, once revolutionary, remains central but has been complemented by modern methods such as qPCR, LAMP, CRISPR diagnostics, and NGS. These tools not only enhance pathogen detection but also empower shrimp farmers with real-time, on-site decision-making capabilities.

As shrimp farming expands globally, robust and adaptable diagnostic systems will be critical for **biosecurity, trade assurance, and sustainable production**. The future lies in integrating molecular biology with digital technologies to build an aquaculture sector resilient against the constant threat of emerging pathogens.

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Rooftop Farming: A New Venture of Agriculture



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Introduction:

Rooftop farming is a modern venture of urban agriculture that cultivates crops like vegetables, herbs, and flowers on the unused flat surfaces of city buildings, offering benefits such as enhanced food security, reduced urban heat island effect, improved storm water management, and increased community connection to food production. It provides sustainable solutions for urban environments by utilizing green spaces, creating shorter food supply chains, and improving local



File photo: Source: ARI Patna

ecosystems. Rooftop farming is the practice of growing crops, such as vegetables, herbs, and flowers, on the rooftops of buildings in urban areas to utilize unused space and address food security and sustainability challenges. It uses techniques like container gardening, green roofs, and hydroponics to produce local, fresh food while offering environmental benefits like reduced urban heat, improved storm water management, and lower transportation emissions. Rooftop farming can also provide economic benefits by increasing property values and creating local jobs, and it offers a space for community engagement and education.

Rooftop farming in India is a growing practice driven by urbanization and a desire for sustainable, healthy food sources, offering benefits like increased food security, reduced carbon footprints, and improved air quality. Urban residents grow organic produce in limited spaces using various techniques, including soil-based and hydroponic systems. While challenges like high costs and structural limitations exist, the trend is expanding, supported by emerging businesses and government initiatives, transforming urban landscapes into productive green spaces.

Urban rooftop farming refers to the practice of growing food crops, herbs, and even flowers on the roofs of buildings in cities. This concept takes advantage of the unused flat surfaces on top of commercial, residential, or institutional buildings to cultivate plants. Urban rooftop agriculture uses modern farming techniques such as hydroponics, aquaponics, and traditional soil-based farming methods to grow food in areas where land is scarce or expensive.

With the primary focus being sustainability and accessibility, urban rooftop farming helps cities address food security issues by providing fresh, local produce. It not only saves transportation costs but also reduces the carbon emissions associated with the long-distance transport of food. The rooftops, which typically remain unused, become green, productive spaces that contribute to the well-being of the city and its inhabitants.

Rooftop farming is a modern venture that leverages underutilized urban spaces for agriculture, though it has historical roots in ancient cities like Mesopotamia and Kathmandu. While seen as a new strategy to address urban food security, land limitations, and the urban heat island effect, rooftop farming is an evolution of existing

practices. It offers numerous benefits, including enhanced food security, reduced food miles, improved air quality, and greater community engagement. Urban rooftop farming refers to the practice of growing food crops, herbs, and even flowers on the roofs of buildings in cities. This concept takes advantage of the unused flat surfaces on top of commercial, residential, or institutional buildings to cultivate plants.

History:

Rooftop farming dates back to ancient Mesopotamia, where ziggurats featured planted terraces, and later to Roman times with examples like the Villa of the Mysteries in Pompeii. The practice was revived and reinterpreted by modern architects like Le Corbusier in France in the 1920s, leading to the commercialization and widespread adoption of rooftop gardens in the late 20th century, driven by a need for sustainable food production in urban environments.

Ancient Origins:

- **Mesopotamia:**

Evidence suggests planting on elevated structures, such as the ziggurats, existed as early as the 4th millennium BC.

- **Roman Empire:**

Structures like the Villa of the Mysteries in Pompeii featured elevated terraces for growing plants, demonstrating the early use of elevated spaces for horticulture.

Revival and Modernization

- **1920s: Le Corbusier:**

The Swiss architect Le Corbusier brought the concept of rooftop gardening back into architectural design in his efforts to beautify and integrate green spaces into Paris.

- **Mid-20th Century:**

The idea gained traction and was commercialized in Germany by the 1970s, leading to wider adoption in North America and other urban centers.

Benefits:

Rooftop farming offers numerous benefits, including environmental advantages like reducing the urban heat island effect, improving air quality, and managing stormwater. Socially, it enhances community engagement, promotes mental well-being, and creates urban biodiversity. Economically, it provides local, fresh food, reduces food miles, and can create income opportunities and energy savings for buildings. Rooftop farming also improves the aesthetic appeal of urban spaces and offers residents access to fresher, healthier, and more localized produce.

Environmental Benefits:

- **Urban Heat Island Effect Reduction:**

Plants absorb heat, cooling the surrounding urban environment and buildings.

- **Improved Air Quality:**

Rooftop gardens filter pollutants from the air and release oxygen, while also absorbing carbon dioxide.

- **Stormwater Management:**

Plants absorb rainwater, reducing runoff and the impact on urban stormwater systems.

- **Enhanced Biodiversity:**

Green roofs provide habitats and food sources for beneficial insects and birds, supporting urban wildlife.

- **Energy Efficiency:**

The added insulation from vegetation helps regulate building temperatures, reducing the energy needed for heating and cooling.

Economic Benefits

- **Reduced Energy Costs:**

By insulating buildings, rooftop farms lower energy consumption and associated expenses.

- **Increased Property Value:**

The development of rooftop farms can boost property values and rental income.

- **Hyper-local Produce:**

Access to fresh, locally grown food reduces the need for long-distance food transportation.

- **New Revenue Streams:**

Rooftop farming can create employment and income opportunities for local communities.

Social and Health Benefits

- **Increased Food Security:**

Provides a reliable source of fresh, safe, and nutritious food, particularly in urban areas with limited access to healthy produce.

- **Community Engagement:**

Rooftop gardens can serve as social hubs, fostering community interaction and participation.

- **Mental and Physical Health:**

Exposure to nature and vegetation has been shown to improve mental well-being, and gardening itself is a healthy physical activity.

- **Educational Opportunities:**

Rooftop farms offer a living classroom for learning about urban agriculture, food systems, and sustainability.

Roof Top Farming Disadvantages:

Rooftop farming faces disadvantages including potential structural limitations from the roof's weight capacity and potential damage, extreme weather exposure like intense sun and high winds that can stress plants, and challenges with watering and drainage due to increased evaporation and the need for robust systems. Other drawbacks include higher costs for materials and professional installation, the need for labour and maintenance, potential issues with pest and disease control, and a limited variety of plants that can thrive in such exposed conditions.

Structural and Building Issues

- **Weight Concerns:**

Soil and water are heavy, and not all roofs are designed to handle the added load, potentially requiring structural reinforcements.

- **Water Damage:**

Poor drainage or leaky containers can lead to standing water, which can cause dampness and structural damage to the building.

- **Foot Traffic & Wear:**

The constant use of the roof for gardening can cause wear and tear and requires the roof's structure to be able to support the foot traffic.

Environmental Challenges

- **Extreme Weather:**

Rooftops are exposed to intense sunlight and high temperatures, which can dry out plants quickly, and are also prone to strong winds that can damage seedlings.

- **Water Management:**

Increased sun and wind lead to faster evaporation, making watering difficult, requiring more engineering for effective drip irrigation systems and increasing maintenance efforts.

- **Pest and Disease Control:**

Traditional pest control methods may be harder to apply, and the limited space can make it difficult to prevent the spread of pests and diseases.

Logistical and Financial Burdens

- **High Initial Cost:**

Setting up a rooftop garden can be expensive, requiring significant investment in containers, soil, structural modifications, and professional design for irrigation and drainage systems.

- **Labor and Maintenance:**

Rooftop farming requires considerable time, effort, and labor for watering, weeding, and general care, especially given the added complexity of access and water supply.

- **Limited Space and Plant Variety:**

The use of containers or raised beds can restrict the types of plants that can be grown and may limit the overall variety of crops.

Roof top Farming Practices:

Rooftop farming methods include Container Gardening, Green Roofs, Hydroponics, and Aeroponics, each utilizing different approaches to grow plants on building tops. Container gardening uses various pots and beds with soil-based growing media, while green roofs integrate soil and plants directly onto the roof surface. Hydroponics grows plants in nutrient-rich water solutions, and aeroponics uses mist to deliver nutrients to plant roots without soil. Vertical farming techniques can also be applied to rooftops to maximize space by stacking layers of plants.

Traditional & Soil-Based Methods

- **Container Gardening:**

This is a common method where plants are grown in pots, buckets, grow bags, or other containers. Lightweight soil mixes, compost, or coconut peat can be used to reduce the load on the roof.

- **Green Roofs:**

These systems integrate a layer of soil and plants directly on a roof structure, often for stormwater management and building efficiency. Existing green roofs can be adapted for food production by adjusting the growing medium to support crops.

Soil-Less Growing Methods

- **Hydroponics:**

This technique involves growing plants in a water-based solution enriched with nutrients, without the use of soil. Variations include floating hydroponics for leafy greens and nutrient film techniques.



Source: A rooftop hydroponic farm in the city-Niche farmer (File Photo)

- **Aeroponics:**

Aeroponics uses mist to deliver water and nutrients directly to the roots of plants. This method maximizes oxygen exposure to roots, promoting rapid growth.

- **Aquaponics:**

A combination of aquaculture (raising fish) and hydroponics, where fish waste provides nutrients for the plants, and the plants filter the water for the fish.

Maximizing Space

- **Vertical Farming:**

This method uses stacked layers of plants to maximize crop production in a small area. Rooftop vertical systems can be integrated with soil-based or soil-less techniques.

Key Considerations for Rooftop Farming:

- **Roof Load:**

Ensure the roof's capacity can handle the weight of containers, water, and plants, as this can be a significant load.

- **Lightweight Materials:**

Use lightweight growing media, such as coconut peat and perlite, and lighter-weight containers to reduce roof stress.

- **Water Management:**

Employ efficient irrigation, such as lightweight drip systems, and consider rainwater harvesting to reduce water consumption.

- **Local Regulations:**

Check building codes, homeowner organization rules, or local ordinances before starting a rooftop farm.

The future of urban farming is bright, driven by increasing urbanization, climate change concerns, and technological advancements. AI and other innovative technologies will play a crucial role in optimizing urban farming practices, making them more efficient, sustainable, and resilient. Addressing the challenges related to space constraints, regulatory frameworks, and supply chain development will be essential for unlocking the full potential of urban agriculture and ensuring its contribution to a more sustainable and food-secure future. Utilizing rooftop space for urban farming can increase food production and mitigate the urban heat island effect. Rooftop gardens can also improve air quality and provide aesthetic benefits to urban landscapes. They can range from small-scale community gardens to large-scale commercial operations.

Conclusion:

Rooftop farming is a sustainable future agriculture venture that transforms unused urban spaces into productive gardens using techniques like soil-based, hydroponic, or aquaponic systems. It addresses urban food insecurity by providing local, fresh produce, reduces food transportation costs and emissions, and mitigates climate impacts by improving air quality and reducing the urban heat island effect. While challenges like infrastructure and expertise exist, rooftop farming offers significant environmental, economic, and social benefits, contributing to healthier cities and greater food resilience. **Rooftop vertical farming** and advanced rooftop farming techniques promise to drive the future of sustainable food production in cities. These cutting-edge systems not only enable fresher, local produce but also promote ecological harmony, improve air quality, and reduce agriculture's environmental footprint.



MUSCULOSKELETAL DISORDERS IN AGRICULTURAL WORKERS: CAUSES AND PREVENTION METHODS



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Abstract

Musculoskeletal disorders (MSDs), particularly work-related musculoskeletal disorders (WMSDs), pose a significant occupational health challenge for agricultural workers due to the physically intensive, repetitive, and ergonomically poor nature of farming tasks. This article explores the classification, risk factors, causes, consequences, and preventive strategies associated with WMSDs in agricultural settings. Commonly affected body regions include the lower back, shoulders, neck, knees, and wrists, with conditions such as low back pain, osteoarthritis, and hand arm vibration syndrome being prevalent. Major risk factors found include repetitive movements, awkward postures, heavy lifting, use of non-ergonomic tools, and prolonged work hours, often worsened by poor environmental conditions and psychosocial stressors. The consequences of WMSDs range from reduced mobility and chronic pain to increased absenteeism and economic burden. To mitigate these impacts, the article emphasizes a multifaceted prevention approach involving ergonomic improvements, administrative controls, worker education, participatory ergonomics, and supportive policies. Effective intervention requires collaboration among workers, employers, and policymakers to enhance occupational health and ensure sustainable agricultural productivity.

Introduction

The world's population primarily obtains their food from agriculture, which also supplies vital raw materials for various industries and medicinal purposes. With the rapidly increasing world population and despite the rising demand for food, agriculture remains the foundation of the world economy. Through the use of contemporary technology like information systems, mechanized machinery, and even robotics to supplement or replace manual labor, agricultural production has seen tremendous developments over time. Agriculture continues to be one of the most taxing and dangerous professions, with one of the highest rates of work-related illnesses, injuries, and deaths in spite of these advancements.

Musculoskeletal disorders (MSDs)

Disorders of the Musculoskeletal System are injuries or disorders affecting the body's muscles, joints, tendons, ligaments, and nerves. They develop over time due to repetitive, strenuous, or awkward physical activities and might vary from slight pain to extreme disability. When these conditions are linked to occupational tasks, they are referred to as Work-related Musculoskeletal Disorders (WMSDs).

Classification of Musculoskeletal Disorders

Musculoskeletal disorders (MSDs) in farmers might be divided into many categories according to the bodily part that is impacted, type of disorder, and associated occupational risk factors. Common MSDs include:

- 1) Osteoarthritis (OA), particularly of the hip and knee, resulting from repetitive joint overloading, strong lifting, and extended standing.
- 2) Low back pain (LBP), including sciatica and herniated discs, is prevalent due to physically demanding tasks like bending, lifting, and tractor driving, which involves whole-body vibration.
- 3) Workers in greenhouses and orchards are more likely to experience upper limb conditions like neck and shoulder pain. Disorders of the elbow, wrist, and hand are more prevalent in some subgroups of farmers than in general farmers (e.g., milkmaids, foresters). These workers are more likely to suffer from repetitive and forceful manual jobs, which can result in carpal tunnel syndrome and epicondylitis.
- 4) Using vibrating instruments puts farmers at risk for hand arm vibration syndrome (HAVS) shown in fig.1 and fig.2.
- 5) Farmers show a higher prevalence of Fibromyalgia, possibly due to chronic physical strain

- 6) A slightly increased risk of Rheumatoid arthritis due to exposure to pesticides or organic solvents. (Bone et al., 2002)



Fig.1. Workers using vibrating instruments



Fig.2. Hands affected by HAVS

Common WMSDs in Agricultural Workers

Agricultural workers are particularly vulnerable to work-related musculoskeletal disorders (WMSDs) due to the physically intensive and repetitive nature of their tasks as shown in fig.3. Commonly reported WMSDs among them include low back pain, often resulting from frequent bending, lifting, or stooping. Shoulder and neck disorders are also prevalent, typically caused by overhead work, repetitive arm movements, or carrying heavy loads. Workers often experience knee and leg pain due to prolonged squatting and kneeling postures. Additionally, repetitive hand use in activities such as cutting or gripping tools can lead to hand and wrist disorders. Upper back strain is another common issue, usually stemming from twisting motions or lifting and carrying heavy objects.



Fig. 3. Different agricultural activities causing musculoskeletal disorders

Principal Risk Factors for MSD Development

Identifying the primary risk factors for the emergence of musculoskeletal diseases (MSDs) in agriculture shows that labor-intensive manual tasks, especially harvesting, are most frequently linked to injuries. Stooping, or prolonged trunk flexion, appeared as the most prevalent risk factor due to its repeated use in low-growing crop activities, contributing significantly to low back pain. Other contributing factors include repetitive movements, awkward postures, heavy lifting and carrying, kneeling, pesticide exposure, aging, gender differences, and the use of poorly designed tools as shown in fig.4. These risk elements are intensified by adverse environmental conditions such as muddy terrain and barefooted work, common in both developed and developing agricultural settings. Collectively, these findings underscore the urgent need for ergonomic interventions tailored to mitigate the biomechanical loads experienced by agricultural workers and to reduce the incidence of MSDs in this labor-intensive sector. (Benos *et al.*, 2020)

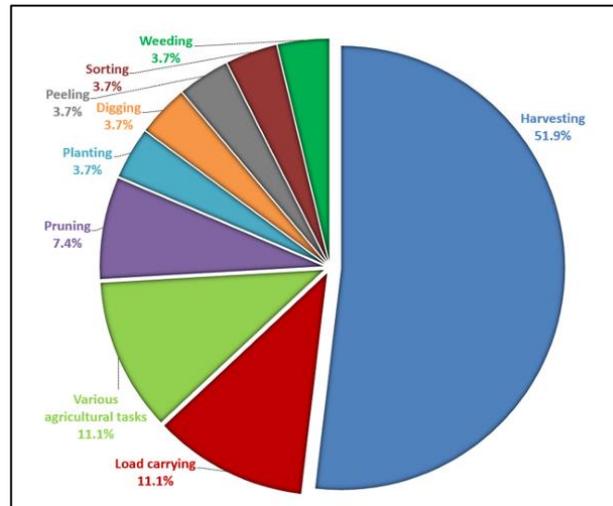


Fig. 4. The distribution of manual tasks that lead to musculoskeletal Disorders

Causes of WMSDs in Agricultural Workers

The causes of work-related musculoskeletal disorders (WMSDs) in agricultural workers are multifactorial and arise from a combination of physical and psychosocial risk factors. Repetitive motions, such as those involved in planting, weeding, or harvesting, are performed for extended periods and place constant stress on the body. Awkward postures, including prolonged stooping, squatting, or kneeling, contribute significantly to musculoskeletal strain. Manual material handling (MMH), such as lifting or carrying heavy loads like fertilizer sacks or produce bins, further increases the risk of injury. The use of poorly designed or non-ergonomic tools worsens strain on the hands, wrists, and shoulders. Additionally, long working hours with limited rest periods reduce muscle recovery time, compounding the risk of injury. Psychosocial stressors such as job insecurity, financial pressure, and time constraints also play a role by contributing to muscle tension and chronic pain.

Consequences of WMSDs

Work-related musculoskeletal disorders (WMSDs) have serious penalties for both the health of agricultural workers and overall farm productivity. Affected individuals often experience reduced physical function and mobility, which impairs their ability to perform work-related and daily activities. Chronic pain and fatigue are common, diminishing quality of life and contributing to rising healthcare expenses. These conditions often lead to increased absenteeism and labor shortages, particularly during critical periods like planting or harvesting seasons. Additionally, WMSDs impose a significant economic burden due to the costs of medical treatment, lost productivity, and potential compensation claims.

Prevention and Control Measures

Preventing WMSDs in agriculture requires a combination of ergonomic, organizational, and educational interventions:

1. Ergonomic Interventions

- Redesigning tools and equipment to reduce strain like adjustable hoe, padded handles.
- Introducing mechanization where possible, such as harvest carts or mechanized planters.
- Adjusting workstations to reduce stooping and bending.

2. Administrative Controls

- Implementing rest breaks and job rotation to minimize prolonged exposure to repetitive tasks.
- Scheduling tasks to avoid peak sun and fatigue hours.

3. Education and Training

- Teaching farmers about safe lifting techniques, posture correction, and the importance of stretching.
- Promoting awareness of early symptoms of WMSDs to seek prompt treatment.

4. Participatory Ergonomics

- Involving workers in the design and implementation of ergonomic solutions ensures relevance and sustainability.

5. Policy and Institutional Support

- Development of occupational safety regulations tailored for informal agricultural workers.
- Access to health surveillance, ergonomic assessments, and social protections.

Conclusion

Work-related musculoskeletal disorders (WMSDs) remain a critical occupational health challenge in agriculture, primarily due to repetitive tasks, awkward postures, and heavy physical workloads. These conditions not only cause chronic pain and disability but also negatively impact farm productivity and workers' quality of life. The multifactorial nature of WMSDs highlights the need for integrated preventive measures, including ergonomic interventions, administrative strategies, and farmer education. Promoting participatory ergonomics and ensuring institutional and policy support can further strengthen prevention efforts. By prioritizing occupational health, agricultural systems can achieve both improved worker well-being and sustainable productivity.

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Remote sensing in Fisheries and Aquatic Environment



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Abstract

Fisheries and aquaculture are important sectors playing role in providing nutritional security to the world. In recent times aquaculture is considered as a relatively sustainable option compared to the wild capture of fishes and often involves reduction in input costs, optimization of outputs and strategies to reduce pollution. Recent innovations are changing aquaculture and making it more efficient, sustainable, and technologically advanced. The use of technologies like the Internet of Things (IoT), artificial intelligence (AI), and robotics is leading this change. These innovations allow farmers to monitor and control important factors such as water quality, temperature, and feeding in real time. Remote sensing use in the field of aquaculture, fisheries and monitoring of aquatic environments is one of such innovations. The present article discusses briefly the principle of remote sensing and its application in fisheries and aquaculture and aquatic environments.

Introduction

Remote sensing is a scientific method of obtaining information about objects or areas from a distance, typically using satellite or airborne sensor technologies. The fundamental principle of remote sensing involves the detection and measurement of radiation of different wavelengths reflected or emitted from distant objects or materials, which is then used to identify and characterize them.

At its core, remote sensing relies on the interaction between electromagnetic radiation and matter. The sun or an artificial source emits electromagnetic energy, which interacts with the Earth's surface and atmosphere. Depending on the properties of the material—such as reflectance, absorption, and emission—different wavelengths of this energy are captured by sensors. The data collected are then processed and interpreted to extract meaningful information about the target objects or environments.

Remote sensing systems are typically classified based on the source of energy. Passive remote sensing systems detect natural radiation that is emitted or reflected by the object or surrounding areas, commonly sunlight. In contrast, active systems emit their own energy (e.g., radar or LiDAR) and record the amount of energy reflected back.

The principle of spectral signature underpins the ability of remote sensing to discriminate between different features. Each material reflects and absorbs electromagnetic energy in a unique pattern across various wavelengths. This distinctive pattern, or spectral signature, enables identification and classification of surface materials, such as vegetation, water bodies, or urban structures. Modern advancements in sensor technologies and data processing algorithms have greatly enhanced the spatial, spectral, and temporal resolution of remote sensing, making it a critical tool in applications such as environmental monitoring, agriculture, urban planning, and disaster management.

Remote Sensing in Fisheries

Remote sensing has emerged as a powerful tool in the field of fisheries, providing critical insights for monitoring marine environments, managing fish stocks, and supporting sustainable fisheries. The technology offers synoptic, repetitive, and non-intrusive data collection capabilities, which are particularly valuable in assessing oceanographic conditions that influence fish distribution and abundance.

One of the most prominent applications of remote sensing in fisheries is in the monitoring of sea surface temperature (SST), chlorophyll-a concentrations, and ocean color. These parameters are essential indicators of primary productivity and can be used to locate potential fishing zone. For example, satellite-derived chlorophyll-a data from sensors such as MODIS and SeaWiFS help identify regions of high phytoplankton biomass, which serve as feeding grounds for many pelagic fish species.

Remote sensing is also instrumental in mapping and monitoring fish habitats, including coral reefs, estuaries, and mangrove ecosystems. High-resolution satellite imagery enables the identification of critical habitats and assessment of habitat degradation over time (Mumby et al., 2004). Furthermore, radar and optical sensors are used to detect fishing vessel activities, helping in the surveillance and regulation of illegal, unreported, and unregulated (IUU) fishing.

In aquaculture, remote sensing supports site selection by evaluating water quality parameters, temperature regimes, and coastal topography. This reduces ecological impacts while optimizing production conditions. Remote

sensing data, combined with Geographic Information Systems (GIS), enhance the modeling and forecasting of fishery resources, enabling data-driven decision-making for policy and conservation.

Overall, remote sensing contributes significantly to the development of ecosystem-based fisheries management by providing real-time environmental data and long-term trends crucial for understanding the dynamics of aquatic ecosystems.

Remote Sensing in Different Aquatic Environments (Excluding Fisheries)

Beyond fisheries, remote sensing plays a crucial role in the monitoring and management of various aquatic environments such as wetlands, lakes, rivers, and coastal zones. It offers a cost-effective, scalable, and time-efficient means to observe hydrological dynamics, water quality, aquatic vegetation, and ecological changes over time.

In freshwater systems, remote sensing is extensively used to monitor surface water extent and dynamics, particularly in floodplain mapping and lake/reservoir level assessment. For example, satellite altimetry and multispectral data enable long-term observation of lake surface area variations and river discharge estimates. Synthetic Aperture Radar (SAR), with its cloud-penetrating capability, is particularly effective in monitoring wetlands and inundated areas.

Water quality assessment is another vital application. Remote sensors detect parameters such as turbidity, suspended sediments, and dissolved organic matter. These proxies are critical for understanding eutrophication, algal blooms, and pollution events in lakes and estuaries. The Sentinel-2 and Landsat missions have been instrumental in this regard, offering high-resolution imagery for chlorophyll-a mapping and trophic state classification of inland.

In coastal and estuarine environments, remote sensing supports shoreline change detection, sediment transport analysis, and salinity gradient mapping. It is also valuable for assessing the impacts of sea-level rise and human interventions such as land reclamation. Hyperspectral imaging helps in identifying and mapping submerged aquatic vegetation and benthic habitats, enhancing conservation planning.

Thus, remote sensing significantly enhances our ability to monitor, understand, and manage aquatic environments across diverse geographic scales and ecological settings.

Recent Advances in Remote Sensing and Future Perspectives

Recent advances in remote sensing are transforming how we observe and understand Earth systems, with innovations spanning sensor technologies, data analytics, and satellite missions. The integration of high-resolution spatial, spectral, and temporal data with emerging technologies such as artificial intelligence (AI), machine learning (ML), and cloud computing is enabling unprecedented accuracy and scale in environmental monitoring and modelling.

One of the most significant developments is the launch of advanced multispectral and hyperspectral sensors. Missions such as ESA's Sentinel-2, NASA's ECOSTRESS, and the upcoming Surface Biology and Geology (SBG) mission provide detailed spectral data to monitor terrestrial and aquatic ecosystems, vegetation traits, and even biochemical compositions. Meanwhile, LiDAR and SAR (Synthetic Aperture Radar) systems have seen expanded use for 3D mapping, biomass estimation, and change detection in both terrestrial and aquatic landscapes.

Cloud-based platforms like Google Earth Engine (GEE) have revolutionized remote sensing data processing, offering access to petabyte-scale datasets and powerful computing tools. These platforms facilitate near-real-time monitoring of deforestation, urbanization, water availability, and climate-related variables.

In parallel, AI and deep learning approaches are increasingly applied for automated feature extraction, land use classification, and anomaly detection, making data interpretation faster and more accurate. Additionally, the increasing use of CubeSats and commercial constellations like PlanetScope and ICEYE is reshaping the satellite landscape by providing high-frequency, moderate-resolution imagery at lower cost.

Looking ahead, the future of remote sensing lies in enhanced interoperability among platforms, the democratization of data access, and the fusion of Earth observation with socio-economic and in-situ datasets. Future missions are expected to focus on climate resilience, carbon monitoring, and biodiversity assessment, providing critical data to support the United Nations Sustainable Development Goals (SDGs).

Ultra-Processed Foods: Hidden Threats to Health and Sustainability



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Abstract:

Ultra-processed foods (UPFs), characterized by industrial formulations rich in added sugars, unhealthy fats, sodium and chemical additives, have become a dominant part of modern diets worldwide. While initially food processing improved safety and preservation, the rapid expansion of UPFs has been linked to poor nutritional quality, increased obesity, cardiovascular diseases, diabetes, cancers, and mental health disorders. Their widespread consumption is driven by affordability, convenience, sensory appeal and aggressive marketing, particularly targeting children, which further amplifies long-term health risks and dietary dependence. Beyond individual health, UPFs impose substantial societal and environmental burdens, including higher healthcare costs and unsustainable food production systems. Despite robust epidemiological evidence, controversies persist regarding their classification and the precise mechanisms underlying health risks, creating challenges for effective policy and public health messaging. Comprehensive strategies spanning education, improved labelling, fiscal policies and community-level interventions are urgently needed to curb UPF consumption and promote minimally processed, nutrient-rich alternatives. Future research should focus on mechanistic insights, child-focused dietary impacts and sustainable policy frameworks to mitigate the rising global burden of UPFs.

Keywords: Ultra-processed foods, Public health, Chronic diseases, Children nutrition, Policy interventions and Food sustainability.

Introduction:

Research on ultra-processed foods (UPFs) has emerged as a critical area of inquiry due to their pervasive presence in global diets and their implications for public health and food systems. The concept of UPFs has evolved over recent decades, with the NOVA classification system, introduced in the early 2000s, becoming the predominant framework to categorize foods based on processing levels (Baker et al., 2020) (Monteiro et al., 2019) (Elizabeth et al., 2020). Initially, food processing was recognized for its role in food safety and preservation, but the rise of UPFs—industrial formulations with multiple additives and minimal whole food content—has shifted attention toward their nutritional and societal impacts (Ubbink & Levine, 2024) (Gibney, 2019). UPFs now contribute over 50% of daily caloric intake in many high-income countries and are rapidly increasing in low- and middle-income nations, marking a significant nutrition transition with broad implications for chronic disease prevalence and environmental sustainability (Baker et al., 2020) (Chadha et al., 2024) (Passos, 2024).

The specific problem addressed is the widespread consumption of UPFs characterized by high energy density, excessive sugars, fats, and additives, which are linked to adverse health outcomes including obesity, cardiovascular diseases, diabetes, and mental health disorders (Ahmed et al., 2024) (Dai et al., 2024) (Henney et al., 2024). Despite growing epidemiological evidence, critical knowledge gaps remain regarding the drivers of UPF consumption, especially among children, the mechanisms underlying health risks, and the effectiveness of policy interventions (Smuszkiwicz-Rózański et al., 2024) (Petridi et al., 2023) (Ferretti & Malorgio, 2024).

Controversies persist about the definition and classification of UPFs, with some scholars questioning the causal role of processing per se versus nutrient composition (Wang & Sun, 2024) (Gibney, 2019). These debates complicate public health messaging and policy formulation, underscoring the need for comprehensive synthesis

of current evidence (Lawrence, 2022). Failure to address these gaps risks perpetuating the global burden of non-communicable diseases and environmental degradation.

Ultra-processed foods (UPFs) are industrial formulations typically containing little or no whole foods and are characterized by high levels of added sugars, unhealthy fats, and chemical additives. These foods have become a significant part of modern diets, contributing to various health issues. The increasing consumption of UPFs is driven by factors such as aggressive marketing, convenience, and affordability, but it raises significant health concerns, particularly for children. The societal burden of UPFs is substantial, necessitating policy interventions and strategies to reduce their consumption. Future research is needed to further understand their impact and develop effective reduction strategies.

Classification:

The **NOVA food classification system** is one of the most widely used frameworks for categorizing foods based on the extent and purpose of processing, rather than just nutrient content. It was developed by Brazilian researcher **Carlos Monteiro and colleagues** and is often used in public health and nutrition research. The system divides foods into **four groups**:



Figure 1: Nova Food Classification Source: (Giannakis et al.,2024)

1. Unprocessed or Minimally Processed Foods

Definition: Natural edible parts of plants (fruits, vegetables, seeds, nuts, roots, tubers, grains, legumes) or animals (meat, fish, eggs, milk), as well as fungi, algae, and water.

Processing involved: Cleaning, removal of inedible parts, freezing, drying, grinding, pasteurization, refrigeration, fermentation (without additives), vacuum-packing, or simple packaging.

Examples: Fresh fruits and vegetables, grains, plain milk, eggs, raw nuts, plain yogurt, fresh meat, frozen vegetables.

2. Processed Culinary Ingredients

Definition: Substances obtained directly from Group 1 foods or from nature, used to prepare, season, and cook foods.

Processing involved: Pressing, refining, grinding, milling, or drying.

Examples: Oils, butter, sugar, salt, starch, honey, vinegar.

3. Processed Foods

Definition: Relatively simple products made by adding salt, sugar, oil, or other Group 2 ingredients to Group 1 foods.

Processing involved: Preservation methods like canning, bottling, smoking, or fermentation (with additives such as salt or sugar).

Examples: Canned vegetables, fruit in syrup, cheese, bread (traditional, with few ingredients), smoked fish, salted nuts.

4. Ultra-Processed Foods (UPFs)

Definition: Industrial formulations typically with **five or more ingredients**, often including substances not commonly used in home kitchens (e.g., hydrolyzed proteins, modified starches, hydrogenated oils, flavor enhancers, colorants, emulsifiers, artificial sweeteners).

Processing involved: Multiple industrial processes such as extrusion, moulding, hydrogenation, pre-frying, chemical modification, and packaging designed for hyper-palatability, convenience, and long shelf life.

Examples: Soft drinks, packaged snacks, instant noodles, reconstituted meat products, breakfast cereals with additives, frozen ready-to-eat meals, candies.

Characteristics of Ultra-Processed Foods

UPFs are defined by their high content of added sugars, unhealthy fats, and chemical additives, often resulting in energy-dense products with low nutritional value (Mehboob, 2023) (Khoiriyah et al., 2024). The pervasive presence of UPFs in diets has been linked to increased risks of obesity, cardiovascular diseases, and other chronic conditions, underscoring the urgent need for public health initiatives to promote healthier eating habits (Mehboob, 2023). To combat the rising prevalence of UPF consumption, it is essential to promote awareness about their health risks and encourage the adoption of whole, minimally processed foods as healthier alternatives.

They are typically low in essential nutrients such as fiber, protein, vitamins, and minerals (Shim, 2025). This deficiency in essential nutrients further exacerbates the health risks associated with UPF consumption, highlighting the need for dietary education and improved food policies to support healthier choices. The characteristics of UPFs necessitate a comprehensive approach that includes public awareness campaigns, improved food labelling, and policy measures aimed at increasing the availability of nutritious food options (Mehboob, 2023). By fostering an environment conducive to healthier eating, we can mitigate the negative health impacts associated with UPF consumption.

Common examples include sugar-sweetened beverages, packaged snacks, and ready-to-eat meals (Krieger & Freudenberg, 2022). These products often contain high levels of trans fats, sugars, and sodium, which can contribute to poor dietary quality and increase the risk of chronic diseases (Ahmed et al., 2024). Addressing these health risks requires a multifaceted approach that includes public health campaigns and policy interventions to promote healthier dietary patterns.

Drivers of Consumption

Aggressive marketing strategies by food and beverage corporations significantly drive the consumption of UPFs, especially among children (Krieger & Freudenberg, 2022). To effectively reduce the consumption of ultra-processed foods, it is crucial to implement comprehensive strategies that encompass education, regulation, and community engagement.

The convenience and affordability of UPFs make them appealing to consumers, particularly in low-income and marginalized communities (Krieger & Freudenberg, 2022) (Woods et al., 2022). Efforts should focus on creating supportive environments that promote access to healthier food options while addressing the underlying factors that contribute to the reliance on ultra-processed foods.

The sensory appeal and addictive nature of UPFs also contribute to their widespread consumption (Mehboob, 2023). These factors highlight the urgent need for effective interventions that can reduce the prevalence of UPFs in diets and promote healthier eating habits across all demographics.

Health Concerns

UPF consumption is associated with an increased risk of obesity, cardiovascular diseases, type 2 diabetes, and certain cancers (Zhang & Giovannucci, 2022) (Mehboob, 2023) (Kliemann et al., 2022). The high levels of added sugars and unhealthy fats in UPFs contribute to poor diet quality and chronic health conditions (Mehboob, 2023) (Barbaresko et al., 2024). Processing techniques can lead to the formation of potentially harmful substances, further compromising health (Mehboob, 2023).

Impact on Children

UPFs account for a significant portion of energy intake among children, contributing to weight gain and cardiometabolic risks (Krieger & Freudenberg, 2022) (Petridi et al., 2023). The high prevalence of UPF consumption among children underscores the need for targeted public health initiatives and policies aimed at promoting healthier dietary choices and reducing associated health risks (Ribeiro et al., 2022). Early exposure to UPFs can lead to taste preferences for sweet and unhealthy foods, perpetuating poor dietary habits (Krieger & Freudenberg, 2022). This early conditioning may also influence long-term eating behaviors, making it essential to address these patterns through education and intervention strategies focused on healthier food choices. Disparities in UPF consumption are evident, with higher intake among children from low-income and minority backgrounds (Krieger & Freudenberg, 2022). Addressing these disparities requires tailored interventions that consider socioeconomic factors, ensuring all children have access to nutritious food options and education about healthy eating habits.

Societal Burden

The high demand for UPFs contributes to unsustainable agricultural practices and environmental strain (Mehboob, 2023). Addressing the societal burden of UPFs necessitates a comprehensive approach that includes sustainable agricultural practices, public awareness campaigns, and policies aimed at reducing their consumption while promoting healthier alternatives. UPFs are linked to increased healthcare costs due to their association with chronic diseases (Dai et al., 2024). The financial burden associated with UPFs highlights the need for urgent public health policies that can effectively reduce consumption and promote healthier dietary habits. The societal burden includes the impact on public health systems and the economy due to the prevalence of diet-related diseases (Woods et al., 2022). The economic implications of UPF consumption extend to increased healthcare costs and lost productivity, necessitating a coordinated response from policymakers to promote healthier dietary choices and reduce the reliance on these foods.

Policy Perspectives

Policies aimed at reducing UPF consumption include public awareness campaigns, improved food labeling, and restrictions on marketing to children (Mehboob, 2023) (Woods et al., 2022). Effective policy interventions are crucial to creating an environment that encourages healthier food choices and mitigates the negative impact of ultra-processed foods on public health. Some countries have implemented taxes on sugar-sweetened beverages to discourage consumption (Krieger & Freudenberg, 2022). To effectively combat the rising prevalence of ultra-processed foods, it is essential to implement comprehensive strategies that incorporate education, regulation, and community engagement aimed at promoting healthier dietary patterns (Mehboob, 2023). There is a need for comprehensive policies that promote the availability and affordability of healthier food options (Woods et al., 2022). Such policies should also focus on improving food environments in low-income areas to ensure equitable access to nutritious foods and reduce reliance on ultra-processed options.

Reduction Strategies

Encouraging the consumption of whole, minimally processed foods can help reduce UPF intake (Mehboob, 2023). This can be achieved through community programs, educational initiatives, and policy measures that prioritize the accessibility and affordability of healthier food choices. Educating consumers about the health risks associated with UPFs and promoting nutrient-rich diets are crucial strategies (Mehboob, 2023). Additionally, fostering partnerships between government, industry, and community organizations can enhance efforts to create supportive food environments that prioritize health and nutrition. Policy interventions should focus on creating environments that support healthy food choices (Woods et al., 2022). This includes implementing zoning laws to limit the density of fast-food outlets and enhancing access to fresh produce in underserved areas.

Future Research Needs

Further research is needed to explore the specific health impacts of different types of UPFs and the mechanisms underlying these effects (Zhang & Giovannucci, 2022) (Petridi et al., 2023). Understanding the nuances of UPF consumption is critical for developing targeted interventions that address both public health concerns and the socio-economic factors influencing dietary choices. Studies should investigate the long-term safety of low-calorie sweeteners used in UPFs, especially for children (Krieger & Freudenberg, 2022). This research should also investigate the effectiveness of various educational campaigns aimed at different demographics to enhance

understanding of the health implications associated with ultra-processed food consumption. Research should also focus on the environmental impact of UPF production and consumption (Kliemann et al., 2022). This includes assessing the sustainability of agricultural practices and the carbon footprint associated with the production and distribution of ultra-processed foods.

Table:1 Comparative Insights from Key Studies on Ultra-Processed Foods: Definitions, Drivers, Health Impacts and Policy Perspectives

Study	Definition Consistency	Consumption Drivers	Health Impact Assessment	Policy Effectiveness	Research Gaps and Priorities
(Ubbink & Levine, 2024)	Discusses multiple classification schemes, highlights formulation-based definitions	Highlights product development and industry drivers	Links UPFs to poor diet quality and health risks	Calls for stakeholder engagement for sustainable diets	Emphasizes need for broad engagement and reformulation research
(Ahmed et al., 2024)	Defines UPFs by processing degree and additives	Examines global consumption trends and socio-cultural factors	Details metabolic effects and chronic disease risks	Advocates for awareness and strategy interventions	Calls for strategies addressing individual and societal factors
(Wang & Sun, 2024)	Uses NOVA classification, notes variability in nutrient profiles	Notes global surge in UPF consumption	Focuses on diet quality's role in health outcomes	Suggests focus on nutrient-dense foods over processing alone	Recommends research on metabolomics, microbiome, sustainability
(Khoiriyah et al., 2024)	Defines UPFs by additives and sensory mimicry	Uses diverse data sources to link consumption with obesity	Links UPF intake to obesity and metabolic syndrome	Highlights need for better dietary policies	Calls for policies to mitigate UPF adverse impacts
(Dai et al., 2024)	Uses NOVA system, meta-analyses confirm UPF-health associations	Quantifies UPF intake and health outcome associations	Strong evidence for chronic diseases and mental health risks	Suggests low UPF diets for public health benefits	Identifies need for mechanistic research
(Juil & Bere, 2024)	Reviews evidence supporting NOVA classification	Summarizes global consumption and health associations	Links UPFs to obesity, CVD, diabetes, mortality	Supports dietary guidelines limiting UPFs	Calls for studies on mediating mechanisms
(Lane et al., 2024)	Umbrella review using NOVA, assesses evidence credibility	Analyzes large pooled data on UPF exposure	Convincing evidence for cardiometabolic and mental health risks	Supports population-based measures to reduce UPF intake	Urges urgent mechanistic research
(Zhang & Giovannucci, 2022)	Comprehensive review of UPF definitions and nutrient profiles	Discusses demographic, socioeconomic, behavioral drivers	Reviews longitudinal evidence on health outcomes	Notes challenges in policy and research	Highlights need for high-quality epidemiologic studies

Conclusion:

Ultra-processed foods have become deeply embedded in global diets, posing serious risks to human health, children's nutrition and environmental sustainability. Their rising consumption driven by affordability, convenience and aggressive marketing has been strongly linked to obesity, chronic diseases and increased healthcare burdens. Addressing this challenge requires a multi-pronged approach involving public awareness,

strict regulations, improved labelling, and promotion of minimally processed, nutrient-rich alternatives. Future research and policy action are vital to safeguard public health and build sustainable food systems.

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Tetrazolium Test - A Quick Test to Assess Seed Viability



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Introduction:

The relatively long periods of time required for completion of Germination tests it hinders the progress towards greater efficiency in seed processing this has necessitated the development of acceptable and rapid method for estimating seed viability as it checks its Genetic purity ie Tetrazolium test.

Tetrazolium test: Index or measure of Respiration Process inside living cells , tissue and seed. It's an Estimation of viability at one point of time.

Why it is needed?

Tetrazolium test ensures seed Aliveliness and its quality hence it is achieved by testing the seed viability .by utilizing high quality seeds ,farmers can expect assured yield thereby the standard of living will be improved as it adds to Indian economy.Tetrazolium test is involved in quality control of seeds and determination of vigour index especially for seeds of common bean,corn, cotton ,peanut ,soyabean and wheat and seeds of forage and Horticultural species.

Importance of Tetrazolium test

1. As Tetrazolium test is rapid which can be finished less than two days
2. For the evaluation of seed viability
3. This method has been widely used by scientists to assess germination potential
4. To determine the extent seed damage
5. Also to evaluate seed vigour and or the other seed lot problems

Principle of Tetrazolium test

In this test, living cells are made visible by reducing a indicator dye it in a colourless solution of Tetrazolium salt (2,3,5 Triphenyl Tetrazolium chloride within tissues it interferes with reduction process by accepting a hydrogen from hydrogenases.by hydrogenation of salt, a red, stable and non diffusible substance Triphenyl formazon is produced the reaction is,



Thus it makes to distinguish the red coloured living parts of seeds from colourless dead ones.

- Completely stained are viable seeds and (Viability indicates aliveness of seed)
- Completely unstained are non viable seeds
- Partially stained seeds may occur the presence of necrotic area in embryo determine whether seeds are viable or non viable (Moore 1962)

The inputs needed for Tetrazolium testing

- Testing sample
- Equipments (staining dishes ,cutting and piercing devices eg Razor blade forceps,magnifying devices like lens and microscope ,Medicine dropper,dispensing Bottle,Needles,conditioning media and oven or incubator.
- Preparation of solutions: Dissolve 9.078 g of KH₂PO₄ in 1000 ml of water
Dissolve 11.876 g of Na₂HPO₄ .2H₂O IN 1000 ml of water

Methodology :

Seeds should be soaked in water overnight at room temperature.

The soaked seeds should be cut longitudinally (Monocots) and seed coat is removed(Dicots)

Then seeds should be soaked in 1%Tz solution and kept in dark condition at about 30 degrees for 3 to 4 hours

Stained seeds should be drained off by rinsing it with distill water and evaluate subsequently

If evaluation is difficult on same day then stained seeds should be kept in a Refrigerator for 1-2 days.

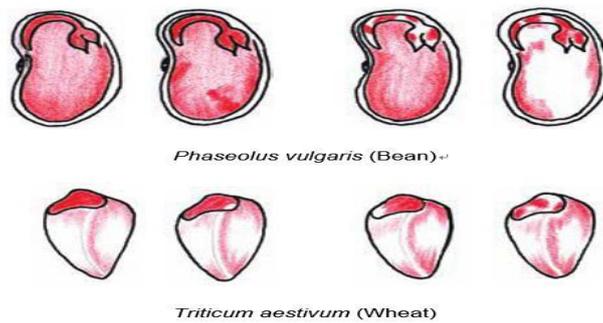


Fig. 1. Staining of French bean and wheat seeds (Steiner, 1997)

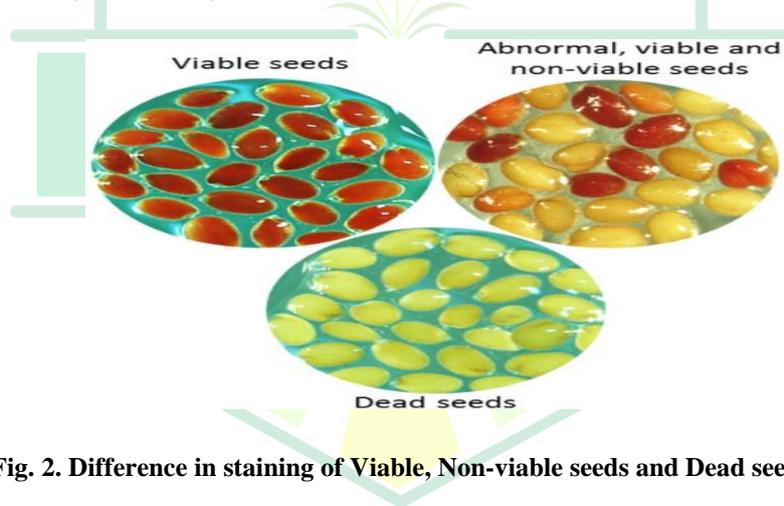
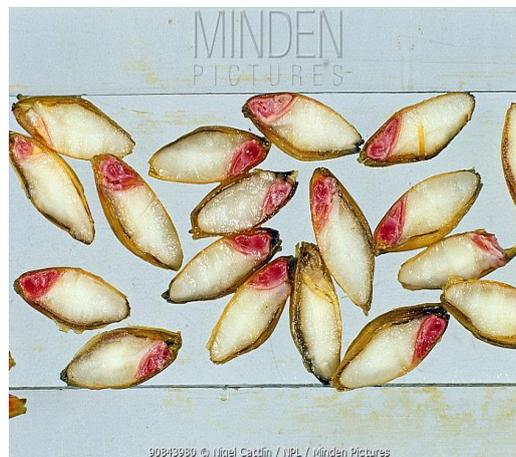
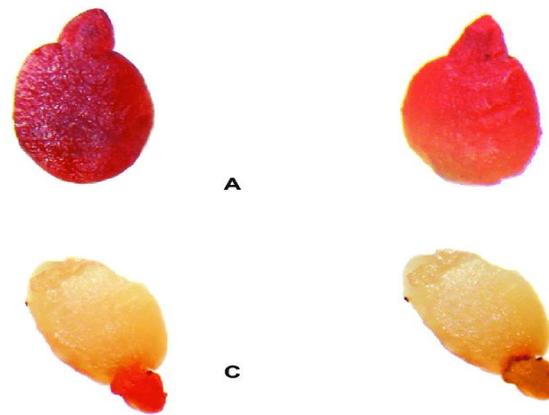


Fig. 2. Difference in staining of Viable, Non-viable seeds and Dead seeds



Staining of safflower seeds



Staining of water melon seeds

Major advantages of Tetrazolium test

1. It excludes major environmental disturbances that could seedling growth and evaluation test such as Germination test.
2. Focus evaluation and assessment of seed embryo structure
3. This method consumes less time
4. Allows identification of seed vigour level.
5. Diagnosis of factors effecting seed deterioration
6. Requires simple and Inexpensive equipment

Disadvantages are:

1. Requires training and knowledge of seed structures proper Tetrazolium interpretation.
2. Need expertise to analyse the viability level.
3. It is Tedious due to examination of Individual seeds that requires patience and experience.

Conclusion

Tetrazolium test indirectly determines the Respiratory activity in the cells that make up the seed tissues. and the Test not only measures the percentage of viable seeds in a sample ,it also reflects the ability of those seeds to produce normal seedlings under less than optimum or adverse growing conditions similar to those which may occur in the field that too in short time and as tetrazolium test avoids the germination test to check whether seeds are alive or dead which takes longer time.

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Sorghum: A King of Millets



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Importance

Sorghum, botanically known as *Sorghum bicolor* L.Moench, is a nutritionally rich crop of the Gramineae family and originated in Africa which is presently considered as the fifth most significant crop in the world after wheat, maize, rice and barley. It is a dual purpose crop and is valued both for its grain as well as for its excellent fodder. It forms the major source of staple food among the rural population of Asia and Africa.

Sorghum bicolor featured prominently in its wild grass form in Africa. It is presumed that sorghum was introduced into the East in approximately 700 B.C. on account of the trade route between East Africa and India (via Arabia). Because of its nutritional value, durability, and versatility in cooking, Sorghum is often called as the "King of Millets". It is extensively produced in Africa, China, the United States, Mexico, and India. Sorghum is a drought tolerant crop growing well in sub tropical and tropical regions with 400 mm rainfall.

It is remarkably tolerant to low input levels which gave it an indispensable feature for the areas getting little rainfall. Sorghum can adapt to various environments, especially under water deficiency and warm conditions. Due to this characteristic, the crop is of great utility in the regions with irregular rainfall distribution and high air temperature. Its farming can be expanded to drought-prone (especially moisture deficit) zones as the crop has the remarkable potential to grow under hostile environments consuming minimum input and care.

Nutritional Composition of Sorghum (per 100g)

Nutritional component	Quantity	Nutritional component	Quantity
Protein (g)	9.97	Zn (mg)	1.90
Fat (g)	1.73	Fe (mg)	3.90
Carbohydrate (g)	67.68	Thiamine (mg)	0.35
Crude fibre (g)	10.22	Riboflavin (mg)	0.14
Mineral matter (g)	1.60	Niacin (mg)	2.10
Calcium (mg)	27.60	Folic Acid (mg)	39.4
Phosphorous (mg)	274.00	Vitamins B1 (mg)	0.33
Iron (mg)	3.95	Vitamins B3 (mg)	3.70
Mg (mg)	133.00	Vitamins B6 (mg)	0.44

Health benefits of Sorghum

Sorghum is also rich in dietary fibre and very good sources of micronutrients such as vitamins and minerals. Major portion of sorghum protein is prolamin (kaffirin) which has a unique feature of lowering digestibility upon cooking. It has been reported that sorghum proteins upon cooking are significantly less digestible than other cereal proteins, which might be a health benefit for certain dietary groups.

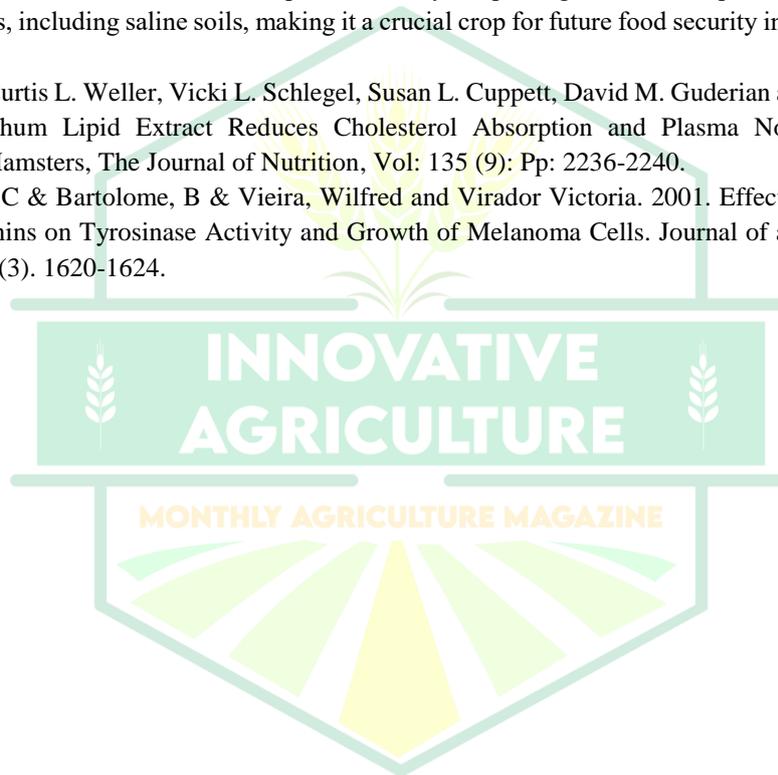
Research findings further indicates that grain sorghum contains components that could be used as food ingredients or dietary supplements to manage cholesterol levels in humans (Carr *et al.*, 2005). Sorghum starch contains 3 to 19 % amylose and 81 to 96.5 % amylopectin. It consists of a Flavanoid *viz.*, 3-deoxyanthocyanin which reacts with carcinogenic cells thus increasing cytotoxicity to cancer cells. Sorghum grains have tannins which have anticancer properties. The polyphenols and tannins present in sorghum have anti-mutagenic and anti-carcinogenic properties and can act against human melanoma cells, as well as positive melanogenic activity (Gomez-Cordovez *et al.*, 2001). The phenolic compound present in sorghum modulates the type II diabetics.

Benefits of sorghum cultivation

- Sorghum is called as a cost effective crop. Because it requires lower production costs and lesser inputs for crop growth when compared to other cereal crops, leading to higher net profits for farmers.
- Sorghum grain has diverse markets. The grain can be used for human food consumption, animal feed, biofuel, edible oils, starch, and other industrial applications, creating multiple income streams for farmers.
- In water deficit areas, sorghum outperforms other crops like maize in water use efficiency, making it a more profitable choice in semi-arid and arid areas.
- Sorghum is highly drought-tolerant, thriving in arid and semi-arid conditions with minimal water, which is a critical advantage in areas facing water scarcity and climate change. Hence it is called as drought tolerant and water efficient crop.
- Sorghum plays a major role in soil health improvement. Its extensive root system helps to improve soil fertility, physical properties, and moisture retention, contributing to overall soil conservation.
- Sorghum is a climate resilient crop. As a hardy crop, sorghum can adapt to various challenging conditions, including saline soils, making it a crucial crop for future food security in a changing climate.

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The Impact of Microalgal Feed Additives on Gut Microbiota and Immunological Responses in Cultured Fish



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Abstract

The intensification of aquaculture necessitates sustainable and efficacious strategies to enhance fish health, growth performance, and disease resistance. Microalgal feed additives have gained significant attention as functional ingredients due to their rich profile of essential nutrients, bioactive compounds, and ability to modulate gut microbiota and immune responses. This review synthesizes current scientific evidence on how microalgal supplementation influences gut microbial ecology and immunological mechanisms in cultured fish species. Key bioactive components such as polyunsaturated fatty acids (PUFAs) pigments and polysaccharides derived from microalgae interact synergistically with the fish gastrointestinal microbiota and immune system enhancing gut health and systemic immunity. Such interactions ultimately promote fish welfare and aquaculture sustainability.

Introduction

Fish gastrointestinal (GI) microbiota plays a pivotal role in nutrient metabolism, immune system development and protection against pathogens. Recent advances elucidate the complexity and dynamic nature of microbial communities colonizing the fish gut, noting their modulation by diet as a critical factor influencing fish health (Wang et al., 2018; Nayak, S. 2010). Microalgae encompassing species such as *Chlorella vulgaris*, *Arthrospira platensis*, *Schizochytrium limacinum* and *Tetraselmis chuii* constitute promising feed additives rich in proteins, essential fatty acids (EPA, DHA) pigments (e.g., astaxanthin, lutein) and immunostimulatory polysaccharides (Mueller. J et al., 2023; Santigosa E. et al., 2021). Leveraging these compounds to favorably alter gut microbial composition and immune responses holds promise for reducing disease outbreaks and improving farming outcomes.

Modulation of Gut Microbiota by Microalgal Feed Additives

The gastrointestinal tract of fish hosts diverse microbial taxa including beneficial bacteria such as *Lactobacillus*, *Bifidobacterium* and *Bacillus* along with opportunistic pathogens like *Vibrio* and *Aeromonas* spp. Diet-induced modulation of this microbiota can alter microbial balance toward health-promoting communities (Nayak, S. 2010; Burr G. et al., 2005). Microalgal polysaccharides and non-digestible components function as prebiotic substrates, selectively fostering beneficial microbes that enhance short-chain fatty acid production and competitive exclusion of pathogens (Burr G. et al., 2005; Denev et al., 2009). Furthermore, phenolic compounds and carotenoids present in microalgae exert antimicrobial effects reducing pathogen proliferation and modulating intestinal epithelial integrity (Mueller. J et al., 2023). Studies with Atlantic salmon reveal that diets supplemented with microalgal derivatives especially broken-cell wall formulations of *Chlorella vulgaris* improved feed conversion and altered fatty acid profiles while inducing microbial and immune-related gene expression changes in the gut (Mueller. J et al., 2023). These molecular changes included differential regulation of proteins involved in host-microbe interactions and inflammatory signaling pathways, underpinning microbiota-immune crosstalk. Integration of next-generation sequencing (NGS) technologies has greatly enhanced the taxonomic resolution and functional understanding of fish gut microbiomes, allowing species-level identification and functional predictions regarding nutrient metabolism, immune modulation and environmental adaptability (Wang et al., 2018; Diwan et al., 2021). Such insights are key to strategically designing microalgal formulations that promote optimal microbiota composition for disease resistance.

Immunological Responses Induced by Microalgal Compounds

Microalgal bioactive compounds impact both innate and adaptive immune responses in fish. Essential fatty acids such as EPA and DHA abundant in species like *Schizochytrium limacinum* demonstrate anti-inflammatory properties by modulating cytokine expression and enhancing antioxidant enzyme activity thus reducing oxidative stress and promoting gut barrier integrity (Mueller, J et al., 2023; Parolini, C. 2019). Pigments including astaxanthin activate innate immunity by stimulating phagocytic activity, lysozyme secretion and respiratory burst functions critical for nearly pathogen defence (Mueller, J et al., 2023). Additionally, microalgal polysaccharides resemble β -glucans, known potent immunostimulants, that engage pattern recognition receptors including Toll-like receptors (TLRs) in gut-associated lymphoid tissue (GALT), which trigger signaling cascades for immune gene expression and cytokine production (Gomez et al., 2008; Machuca et al., 2022). Gene expression studies demonstrate upregulation of complement components (e.g., complement C1q), acute phase proteins, and pro-inflammatory cytokines (IL-1 β , TNF- α) following microalgal feeding, illustrating enhanced immunocompetence (Mueller, J et al., 2023).

However, dosage and species-specific responses necessitate careful optimization to avoid potential immunosuppression or adverse effects. The interplay between gut microbiota and immune responses constitutes a critical axis for fish health. Beneficial microbes stimulated by microalgal prebiotics contribute to immune homeostasis by competitive exclusion of pathogens and production of metabolites that regulate inflammation and maintain epithelial barrier integrity (Gomez et al., 2008; Xiong et al., 2018). These complex interactions support improved disease resistance and recovery post-infection.

Species-Specific Effects and Practical Implications

Studies indicate variable responses to microalgal feed additives depending on fish species, microalgal strain and formulation. For instance, in Atlantic salmon, broken-cell wall *Chlorella vulgaris* enhanced feed efficiency and modulated immune gene expression differently compared to intact cells (Mueller, J et al., 2023). Similarly, in gilthead seabream, microalgal oils replaced fish oil without compromising growth performance, while improving fillet quality and reducing contaminants (Santigosa E. et al., 2021). These species-specific nuances emphasize the importance of tailored feed formulations considering digestibility, bioavailability and environmental condition. From a practical viewpoint, microalgae cultivation, processing (e.g., cell wall disruption) and incorporation protocols critically influence nutrient availability and bioactive compound efficacy. Challenges include maintaining consistent quality at commercial scale and balancing cost-effectiveness with nutritional benefits to maximize adoption in aquafeeds (Mueller, J et al., 2023; Santigosa E. et al., 2021).

Conclusion

Expanding research employing multi-omics approaches, including metagenomics, transcriptomics, and metabolomics, will unveil the mechanistic foundations of microalgal impacts on the fish gut ecosystem and immune responses, enabling the identification of microbial and molecular biomarkers predictive of health status (Diwan et al., 2021; Xiong et al., 2018). Integration of microalgal feed additives with probiotic and prebiotic strategies may synergistically enhance gut health and immunity, contributing to disease prevention in sustainable aquaculture systems (Burr G. et al., 2005; Denev et al., 2009). Long-term feeding trials across diverse species and environmental conditions remain crucial to validate benefits and optimize rates. In conclusion, microalgal feed additives represent a multifaceted tool promoting gut microbiota homeostasis and stimulating robust immunological defenses in cultured fish. Their incorporation into aquafeeds advances sustainable production paradigms by enhancing fish welfare, disease resilience and product quality.

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CENTRAL AND STATE SCHEMES IN AGRICULTURE AND ALLIED SECTORS OF ANDHRA PRADESH



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Central Government Schemes

Pradhan Mantri Kisan Samman Nidhi (PM-KISAN)

The Ministry of Agriculture and Farmers Welfare introduced the Pradhan Mantri Kisan Samman Nidhi (PM-KISAN) in 2019. The program provides direct income assistance of ₹6,000 annually to eligible cultivators and distributed in three equal installments. The scheme is funded entirely by the central government. Small and marginal farmers who own cultivable land are covered under this initiative, while institutional landholders, government officials and individuals with high taxable incomes are excluded.

Pradhan Mantri Fasal Bima Yojana (PMFBY)

Launched in 2016, the Pradhan Mantri Fasal Bima Yojana (PMFBY) is implemented by the Ministry of Agriculture and Farmers Welfare to protect farmers against crop losses caused by natural calamities, diseases and pests. Under this scheme, cultivators pay a nominal premium of 2% for kharif crops, 1.5% for rabi crops and 5% for commercial or horticultural crops while the remaining premium burden is jointly contributed by central and state governments. Participation is compulsory for farmers with crop loans and voluntary for others within the notified regions.

Pradhan Mantri Krishi Sinchai Yojana (PMKSY)

The Pradhan Mantri Krishi Sinchai Yojana (PMKSY), introduced in 2015, is jointly managed by the Ministry of Jal Shakti and the Ministry of Agriculture and Farmers Welfare. Its primary goal, reflected in the motto Har Khet Ko Pani (Water for Every Field) is to expand irrigation facilities and improve water-use efficiency. Support is extended for watershed management, canal development and the adoption of micro-irrigation techniques such as drip and sprinkler systems. Although all farmers are eligible, preference is given to small and marginal farmers willing to adopt modern irrigation practices.

Soil Health Card (SHC) Scheme

Initiated in 2015, the Soil Health Card (SHC) Scheme enables farmers to access detailed reports on the nutrient status of their soil once every two years. These reports guide cultivators in applying balanced fertilizers and following improved agronomic practices. The scheme is universal and benefits farmers across the country.

Rashtriya Krishi Vikas Yojana – Remunerative Approaches for Agriculture and Allied Sector Rejuvenation (RKVY-RAFTAAR)

The Rashtriya Krishi Vikas Yojana (RKVY-RAFTAAR) was launched in 2007 by the Ministry of Agriculture as a centrally sponsored initiative. Funding responsibilities are shared between the central and state governments. The scheme provides states with flexibility to design and execute agricultural development projects according to their local priorities. States and Union Territories that prepare and submit State Agriculture Plans receive financial assistance to promote innovation, entrepreneurship and infrastructure development within the agricultural sector.

Mission for Integrated Development of Horticulture (MIDH)

Established in 2014, the Mission for Integrated Development of Horticulture (MIDH) aims to boost the production and productivity of horticultural crops including fruits, vegetables, flowers, spices, medicinal plants and plantation crops. The scheme benefits farmers, self-help groups, and farmer producer organizations. Assistance is provided in the form of subsidies (40–50%) for planting material, irrigation systems such as drip and sprinkler facilities, mulching sheets and post-harvest infrastructure like pack houses and cold storage units.

Paramparagat Krishi Vikas Yojana (PKVY)

The Paramparagat Krishi Vikas Yojana (PKVY), introduced in 2015 by the Ministry of Agriculture, is designed to encourage organic farming. It promotes the formation of organic farming clusters, each covering at least 50 acres. Farmers within these clusters receive financial support of ₹50,000 per hectare over a three-year period of which ₹31,000 is allocated specifically for organic inputs such as bio-fertilizers, compost and biopesticides. The scheme is fully financed by the central government.

National Livestock Mission (NLM)

Launched in 2014 by the Department of Animal Husbandry and Dairying, the National Livestock Mission (NLM) focuses on enhancing livestock productivity. Key areas include breed improvement, fodder cultivation, and support for poultry and small ruminant farming. The mission provides subsidies to farmers, self-help groups, producer companies and livestock keepers for setting up breed farms, feed plants and other necessary infrastructure.

Rashtriya Gokul Mission

The Rashtriya Gokul Mission, initiated in 2014 by the Department of Animal Husbandry and Dairying, is dedicated to the preservation and genetic enhancement of indigenous cattle breeds. Financial assistance is provided for the creation of Gokul Grams (integrated cattle development centers), bull mother farms and artificial insemination facilities. Beneficiaries include dairy farmers, state livestock boards and cooperative organizations.

Pradhan Mantri Matsya Sampada Yojana (PMMSY)

The Pradhan Mantri Matsya Sampada Yojana (PMMSY) was launched in 2020 by the Department of Fisheries with the objective of doubling fish production, raising aquaculture productivity, and generating employment opportunities in the fisheries sector. Beneficiaries, including fishermen, fish farmers and cooperatives, receive support in the form of subsidies for pond construction, hatcheries, cold chain facilities, fish markets and fishing vessels.

Blue Revolution Scheme

Complementing PMMSY, the Blue Revolution Scheme, launched in 2016, emphasizes the improvement of fish breeding practices, seed production, and the development of inland fisheries. The initiative plays a critical role in strengthening India's fisheries sector and ensuring sustainable aquatic resource management.

Andhra Pradesh State Schemes

Annadatha Sukhibhava

The Annadatha Sukhibhava program, launched in 2019 by the Department of Agriculture, provides annual financial assistance of ₹20,000 to each farmer household. Of this amount, ₹6,000 is contributed by the central government under the PM-KISAN scheme, while the remaining ₹14,000 is provided by the state government. Landless cultivators are eligible to receive the full ₹20,000 directly from the state. All resident farmers, except those employed in government service or belonging to higher income groups, are entitled to benefits under this initiative.

Farm Mechanisation Scheme

The Farm Mechanisation Scheme, relaunched in 2024 under the Sub-Mission on Agricultural Mechanisation, aims to enhance access to modern farm equipment. Managed through the digital Karshak Portal and FM App, the program provides subsidies of up to 50% on agricultural machinery. Within the first 45 days of its relaunch, more than 25,000 farmers availed subsidies worth ₹61 crore. Priority is given to small, marginal and tribal cultivators, particularly those engaged in farming in rainfed areas.

Oil Palm Promotion Scheme

Introduced in 2021 by the Horticulture Department, the Oil Palm Promotion Scheme encourages farmers to adopt oil palm cultivation. The program provides 100% subsidy on saplings and an annual assistance of ₹5,250 per hectare for four years. Additionally, subsidies are extended for the purchase of essential farm machinery such as mini-tractors and choppers. Farmers located in areas identified as suitable for oil palm cultivation are eligible beneficiaries.

Seed and Feed Subsidy Program for Livestock

The Seed and Feed Subsidy Program for Livestock, launched in 2022 by the Department of Animal Husbandry, supports livestock farmers by offering a 75% subsidy on fodder seeds and cattle feed. The program also ensures

free vaccination services and veterinary health care. Furthermore, the state government supplies “Mini-Gokulam” cow shelters to farmers at a token contribution of ₹85. All livestock farmers in the state are eligible for benefits.

Bio and Complex Fertilizer Incentives Program

The Bio and Complex Fertilizer Incentives Program, initiated in 2024 by the Department of Agriculture, seeks to promote the use of bio-fertilizers while ensuring a Minimum Support Price (MSP) for eleven horticultural crops. The scheme also extends procurement and storage assistance for onion farmers and provides targeted financial aid to tobacco growers.

Bamboo (Veduru) Cultivation Promotion Scheme

Launched in 2023 by the Horticulture Department, the Bamboo (Veduru) Cultivation Promotion Scheme promotes bamboo as a sustainable and long-term income-generating crop. Farmers are encouraged to adopt bamboo cultivation, which has the potential to yield earnings of over ₹1 lakh per acre annually once the crop matures. The state is simultaneously developing bamboo processing centers to strengthen market linkages and value addition.

Lift Irrigation Privatization Plan

The Lift Irrigation Privatization Plan, announced in 2024 by the Irrigation and Command Area Development Department, seeks to privatize around 900 lift irrigation schemes covering nearly 8.5 lakh acres. Implemented under the Hybrid Annuity Model, the plan aims to enhance efficiency in water delivery while reducing operational costs for farmers within the command areas.

Micro-Irrigation Expansion Program

Strengthened in 2024, the Micro-Irrigation Expansion Program is a joint initiative of the Departments of Agriculture and Horticulture. The state aims to secure ₹1,110 crore in central assistance to extend micro-irrigation facilities to 15 lakh hectares. Priority is accorded to fruit and vegetable growers. Additionally, under the Market Intervention Scheme, the government guarantees mango procurement at ₹12 per kilogram to safeguard farmers from price fluctuations.

Fertilizer Stock Assurance and Drone Promotion Program

In 2025, the Department of Agriculture introduced the Fertilizer Stock Assurance and Drone Promotion Program to ensure the timely availability of fertilizers, maintaining a buffer stock of nearly 95,000 metric tonnes of urea. The program also promotes sustainable practices by encouraging farmers to adopt drone technology for the spraying of fertilizers and pesticides.

Matsyakara Bharosa Scheme

In the fisheries sector, the Matsyakara Bharosa Scheme provides annual financial assistance of ₹10,000 to fishing families during lean and ban periods. Additionally, the Andhra Pradesh Fishery Policy 2021 promotes aquaculture development through subsidies on seed, feed, aerators, and infrastructure such as ponds and cold storage facilities. Fishermen cooperatives also receive institutional support through the Fishery Cooperative Development Program, which enhances collective bargaining power and improves access to markets.

From Heritage to Healing: Unlocking the secrets of Mediterranean Cypress Oil



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Introduction :

“Nature has always been mankind’s first pharmacy, and among its treasures, Cypress oil stands as a fragrant guardian of health and harmony.”

Distilled from the evergreen *Cupressus sempervirens*, Cypress oil carries centuries of cultural reverence and therapeutic significance. Known for its crisp, woody aroma and wide medicinal value, it has journeyed from the ancient Mediterranean civilizations to today’s aromatherapy rooms and skincare regimens. The Cypress tree itself is a symbol of resilience and longevity, living for up to 600 years and standing tall across diverse regions such as the Mediterranean basin, North America, and tropical Asia. Its oil, extracted from leaves, twigs, and stems, is a natural reservoir of bioactive compounds such as alkaloids, flavonoids, tannins, phenols, and antioxidants that bestow remarkable healing properties. Used historically as a sacred emblem of protection and eternity, Cypress oil today is celebrated not just for its symbolism but for its practical role in enhancing physical wellness and emotional balance. From tightening the skin and soothing respiratory discomfort to calming the mind and refreshing the environment, Cypress oil remains a versatile essence that speaks to both tradition and modern science. Its enduring popularity highlights one truth: in the realm of natural remedies, Cypress oil continues to stand tall, just like the evergreen trees from which it flows.



Fig 1: Cypress tree

About Cypress Tree:

Cypress is the evergreen tree native to Mediterranean region. The genus cypress contains more than twenty species. The cypress trees are distributed among North America, Tropical Asia, Mediterranean region etc., The Scientific name of cypress is called to be *Cupressus sempervirens*. This is also called in common names that includes white cypress, white cypress-pine, Murray River cypress-pine, and northern cypress-pine. It is served as a Symbol of death because it is failed to rejuvenate. It is long lived trees which up to 600 years. The extraction of oil from leaf, twigs and stem of *Cupressus sempervirens*. The leaves consists more range of biological activities and medicinal uses and also leaves have alkaloid content, flavonoids, antidiabetics, antioxidants, tannins, saponins, phenols etc.,

Cypress Oil:

Cypress oil is valued for its wide range of therapeutic properties. Its astringent nature helps tighten tissues, reduce excess oil on the skin, and even control minor bleeding, making it effective in skincare and wound care. As an antispasmodic, it eases muscle cramps, spasms, and even respiratory discomfort such as persistent coughing. The oil also acts as a gentle antiseptic, protecting cuts and wounds from infections. With its crisp, woody fragrance, Cypress oil functions as a natural deodorant, refreshing the body and environment without blocking pores. Its diuretic property aids in flushing out toxins, salt, and excess fluids from the body, thereby reducing swelling and supporting kidney health. Moreover, Cypress oil works as a sedative, calming the nervous system, reducing stress,

and promoting relaxation. By stimulating circulation, it also improves blood flow, helping in conditions like varicose veins and muscle fatigue.

Key Properties of Cypress Oil:

Cypress oil is valued for its wide range of therapeutic properties. Its astringent nature helps tighten tissues, reduce excess oil on the skin, and even control minor bleeding, making it effective in skincare and wound care. As an antispasmodic, it eases muscle cramps, spasms, and even respiratory discomfort such as persistent coughing. The oil also acts as a gentle antiseptic, protecting cuts and wounds from infections. With its crisp, woody fragrance, Cypress oil functions as a natural deodorant, refreshing the body and environment without blocking pores. Its diuretic property aids in flushing out toxins, salt, and excess fluids from the body, thereby reducing swelling and supporting kidney health. Moreover, Cypress oil works as a sedative, calming the nervous system, reducing stress, and promoting relaxation. By stimulating circulation, it also improves blood flow, helping in conditions like varicose veins and muscle fatigue. Lastly, its respiratory-supporting effect makes it useful in clearing congestion and easing breathing difficulties. Altogether, Cypress oil's key properties make it a versatile natural remedy for both physical and emotional well-being.

Extraction Of Cypress Oil:

Extraction of cypress oil can be done through **Hydro distillation(Steam distillation)** method.

Firstly, leaves, stems and twigs that can be collected from the cypress trees. These were dried in shade and mechanically powdered by using high speed blender. The process of essential oil extraction is carried out in **Clevenger apparatus**. Sample is taken in the round bottom flask in which distilled water is added to the sample. 1 gram of plant material requires 100 to 200 ml of water. Then, the sample solution that present in the round bottom flask is gently heated with flame and allowed to pass to the container. Instantly, vapour and steam that are produced through heating collected in the condenser where the vapour gets condensed and cooled back into liquid. Finally, separate the mixture of water from the essential oil by using separating funnel. Owing to its less dense and floating nature on surface of essential oil, where water settles down. Then, the extracted essential oil should be stored in a glass or airtight containers. While in home, it can be extracted using small steam distillers. The oil could be analysed and identified by gas chromatography and mass spectrometry (GCMS).

Benefits And Use :

Cypress oil, derived from the leaves, twigs and stem has numerous benefits. That includes...

- Cypress oil has properties that help to alleviate respiratory issues like coughs and congestion. Its antispasmodic properties can help ease spasms in the respiratory system, promotes easier breathing. This also acts in aromatherapy or steam inhalation.

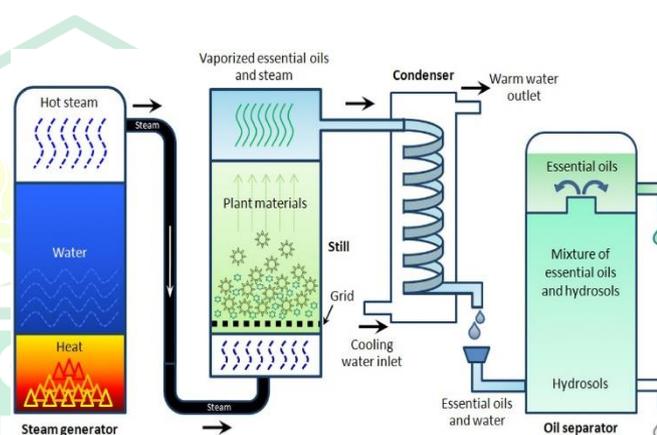


Fig 2: Cypress oil extraction process

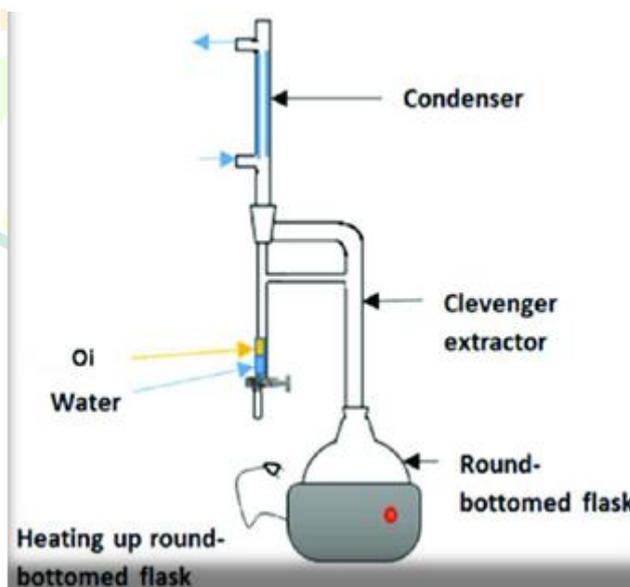


Fig 3: Hydro distillation(Steam distillation)

- Cypress oil exhibits antibacterial and antifungal properties that used in cleaning wounds and preventing infections. It can also be used in skincare against acne-causing bacteria.
- Cypress oil acts as an astringent, tightening and toning the skin. It can be beneficial for oily or acne-prone skin, as well as for reducing excess oil production.
- Cypress oil is known for its calming and grounding effects on the mind and emotions. It may help reduce feelings of stress, anxiety and nervousness, promoting a sense of balance and tranquillity.
- The fresh, woody scent acts as natural deodorizers and air fresheners. It can help to eliminate unpleasant odours and create a clean, refreshing atmosphere.
- Cypress oil may improve circulation and lymphatic flow when used in massage or skincare products.
- The calming aroma of cypress oil can induce relaxation and promote better sleep quality.

Market Trend

Global demand for cypress oil, widely used in skincare, pharmaceuticals, cosmetics, toiletries, aromatherapy, and perfumery, has gained strong momentum in recent years. According to a 2025 report by Global Info Research, the global cypress oil market was valued at USD 72.6 million in 2024 and is projected to grow steadily to USD 119 million by 2031, representing a compound annual growth rate (CAGR) of 7.4 % over that period . This growth is driven by increasing consumer preference for natural and functional ingredients in beauty and wellness products, as well as the versatile aromatic and therapeutic properties of cypress oil.

This growth trajectory has been reinforced by two major global events. Firstly, the COVID-19 pandemic spurred heightened consumer focus on health, hygiene, and stress management, which boosted demand for essential oils especially those marketed for their antimicrobial and calming qualities. Secondly, the Russia–Ukraine conflict exacerbated global supply-chain disruptions and elevated input costs, prompting businesses to diversify sourcing and adjust pricing strategies across personal care and fragrance markets. Together, these factors catalyzed market expansion, making cypress oil increasingly attractive across multiple end-use segments — from skincare and body care to aromatherapy, pharmaceutical formulations, toiletries, and perfumery.

Regional Trends :

The demand for cypress oil is distributed across several key regions, each with distinct drivers. Europe dominates the market due to its well-established perfumery and cosmetic industries, where cypress oil is valued for its woody fragrance and natural toning properties. In North America, the growing popularity of aromatherapy, wellness centers, and spa culture has boosted its use in stress relief and lifestyle products. Meanwhile, the Asia-Pacific region is emerging as the fastest-growing market, driven by traditional medicine practices in India and China, along with expanding cosmetic and personal care industries. Rising disposable incomes and an increasing preference for plant-based formulations are fueling this regional growth.

Sustainability & Ethical Sourcing:

With global consumers becoming more conscious of sustainability, the sourcing of cypress oil is under the spotlight. Overharvesting of cypress trees can pose ecological risks, which has led to a push for controlled cultivation and ethical sourcing practices. Producers are increasingly turning to certifications such as organic, fair trade, and eco-labels to build trust and appeal to environmentally conscious buyers. Companies investing in sustainable distillation practices and transparent supply chains not only protect biodiversity but also gain a competitive edge in premium markets where authenticity and purity command higher prices.

Challenges in the Market:

Despite its growth, the cypress oil market faces several challenges. Adulteration remains a critical issue, with cheaper substitutes often blended into genuine oils, undermining consumer confidence and brand reputation. Price volatility caused by climatic fluctuations, limited production regions, and geopolitical events can disrupt supply and profitability. Additionally, regulatory hurdles in pharmaceuticals and cosmetics demand strict compliance, as



Fig 4: Cypress Oil

unverified health claims can attract scrutiny. Ensuring consistent quality, investing in testing methods, and diversifying supply sources will be essential for producers and manufacturers to overcome these barriers and sustain growth in the long run.

Conclusion:

The *Cupressus sempervirens* used for extracting oil by Hydro distillation process. Cypress oil has many biological activities such as antioxidants and antifungal properties. The scent of Cypress Oil is fresh, herbaceous and woody in nature, making it a perfect companion to those who feel stressed or ‘foggy’ and use the oil to help them feel clear headed and alert. Today, it’s an affordable and easy to access essential oil that helps with a number of issues. Hence, honouring of enduring power of plants and continuing this legacy to these amazing products from cypress trees.

“Heals the soul with demands of replenishing pours of cypress”

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RELATION OF AGRICULTURE AND NUTRITION IN PRESENT SCENARIO



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Abstract

Agriculture and nutrition are closely connected, with agricultural advancements boosting food security primarily through increased calorie production, but there is now a crucial shift toward nutrient security that prioritizes diverse, nutrient-rich foods like fruits, vegetables, legumes, and biofortified crops. Despite progress in hunger reduction, malnutrition remains widespread, manifesting as undernutrition, micronutrient deficiencies, and a rising prevalence of overweight and obesity linked to poor dietary quality and processed foods, resulting in non-communicable diseases. Climate change and growing populations threaten agricultural productivity and food availability, heightening the need for sustainable farming practices such as agroecology and precision agriculture, which improve environmental sustainability and nutritional quality. In India and other countries, agricultural trends are moving toward diversified, higher-value crops and livestock products that align with healthier diets.

To effectively tackle malnutrition, nutrition-sensitive agricultural policies and programs are essential, emphasizing dietary diversity and nutrient-rich foods for vulnerable groups such as pregnant women and children. Agriculture-led growth contributes to poverty reduction and better nutrition among rural smallholder farmers, yet agricultural efforts alone are insufficient. Collaborative, multisectoral approaches involving agriculture, health, and education sectors are crucial for sustainable progress. Addressing malnutrition, a leading cause of child mortality and developmental impairments, calls for intensified production, processing, storage, and equitable distribution of nutritious food. Ultimately, integrated policies focused on food quality, diversity, and sustainability are imperative to advance global nutritional health amid 21st-century challenges.

Introduction

Agriculture and nutrition are inextricably linked in shaping human health and well-being across the globe. Advancements in agricultural productivity have enhanced food security, yet the quality and diversity of food produced remain crucial determinants of nutritional outcomes. In the present context marked by climate change, population growth, and rising non-communicable diseases (NCDs), the synergy between agriculture and nutrition demands renewed attention and integrated policy responses (Farming and Health, 2025).

Agriculture's Role in Nutritional Health

Agriculture is the primary source of food production, directly influencing the availability, diversity, and affordability of nutritious foods crucial for a healthy diet. Traditionally, agricultural policies focused mainly on calorie security—ensuring enough staple crops to feed populations. However, this focus is expanding toward “nutrient security,” emphasizing the production of nutrient-dense foods including fruits, vegetables, legumes, and biofortified staple crops such as vitamin A-enriched sweet potatoes and iron-fortified beans (Ahmad, 2025; Farming and Health, 2025).

Despite significant progress in reducing hunger, malnutrition persists in various forms worldwide. Over 800 million people remain undernourished, deprived of adequate macronutrients and micronutrients, leading to “hidden hunger” from micronutrient deficiencies which impair cognitive development and immunity (Farming and Health, 2025). Conversely, there is a concurrent global rise in overweight and obesity, partly due to the shift towards energy-dense but nutrient-poor processed foods, contributing to NCDs like type 2 diabetes and cardiovascular disease (Farming and Health, 2025).

Agriculture and Nutrition in the Era of Climate and Demographic Challenges

Climate change threatens agricultural productivity by altering weather patterns and increasing pest prevalence, which can reduce crop yields and exacerbate food insecurity, thereby impacting nutritional status globally. The

world population is projected to reach nearly 10 billion by 2050, increasing food demand and the pressure to produce nutritious food sustainably (Farming and Health, 2025). Sustainable agricultural practices such as agroecology, precision farming, and reduced chemical inputs have been highlighted as ways to address these challenges by improving both environmental sustainability and nutritional quality (Farming and Health, 2025; World Bank, 2015).

India's agricultural profile exemplifies this shift from sheer grain production to diversified, higher-value foods that align better with nutrition goals. Over the past decade, the value of high-nutrition horticulture and livestock sectors has grown faster than staple cereals, reflecting a move towards diets richer in fruits, vegetables, dairy, and protein (Ahmad, 2025).

Policy Integration and Future Pathways

Here are some main recent policies of agriculture and nutrition in India and in the world:

India:

1. POSHAN Abhiyaan (National Nutrition Mission) (2018 ongoing) - A flagship program aimed at improving the nutritional status of children, pregnant and lactating women through convergence of various schemes, use of technology (Poshan Tracker), and promoting diversified diets including millets and micro-nutrient fortified foods.
2. Prime Minister Dhan-Dhaanya Krishi Yojana (2025) - Launched to enhance agricultural productivity and irrigation infrastructure in low productivity districts, supporting 1.7 crore farmers along with improving access to credit and skilling for sustainable agricultural growth.
3. One District One Product (ODOP) Scheme (2020s) - Promotes regional balanced development by identifying and boosting cultivation and processing of district-specific agricultural products to increase farmer incomes and diversify food production.
4. Anaemia Mukh Bharat (2018 ongoing) - A multi-sectoral initiative to reduce anemia among women and children through iron-folic acid supplementation, deworming, and nutrition education.
5. National Nutrition Policy (2021-2025) - Focuses on promoting food security, nutrition, and sustainable agriculture by encouraging diversified and safe foods, biofortification, and improving dietary diversity with emphasis on vulnerable groups.
6. Dietary Guidelines for Indians (2024) - Recommended by National Institute of Nutrition, encouraging balanced diets with diverse foods, breastfeeding, moderation of oils and salt, and adequate hydration.
7. Promotion of Millets and Coarse Cereals (2020s) - Policies to encourage production and consumption of nutrient-dense millets and coarse cereals to address micronutrient deficiencies and improve rural incomes.

World:

1. Comprehensive Implementation Plan on Maternal, Infant and Young Child Nutrition (2012) - Endorsed by the World Health Assembly, this plan sets global nutrition targets such as reducing childhood stunting by 40%, decreasing anaemia in women of reproductive age by 50%, and reducing low birth weight by 30% by 2025. It promotes intersectoral collaboration especially across health, agriculture, education, and social support sectors.
2. UN Zero Hunger Challenge (2012) - Launched at the Rio+20 Conference, it aims for zero stunted children under 2 years, 100% access to adequate food all year round, sustainable food systems, doubling smallholder productivity and income, and zero food loss and waste.
3. Sustainable Development Goal 2 (SDG 2) - "End hunger, achieve food security and improved nutrition and promote sustainable agriculture" (2015) with targets including ending all forms of malnutrition by 2030, doubling agricultural productivity of small food producers, and implementing resilient agricultural practices.
4. Dietary Guidelines for Americans 2020-2025 - Issued jointly by the US Departments of Agriculture and Health and Human Services, these guidelines emphasize healthy dietary patterns across the lifespan, including nutrient-dense foods and addressing diet-related chronic diseases.

Agricultural development must integrate nutrition sensitivity to tackle malnutrition comprehensively.

Extension workers and agricultural projects increasingly focus not only on increasing production but also on dietary diversity and consumption of biofortified and nutrient-rich foods, targeting vulnerable populations such as pregnant women and young children (World Bank, 2015). Furthermore, agriculture-led growth is documented to be more effective in poverty reduction, positively influencing nutrition outcomes among rural poor, most of whom are smallholder farmers (World Bank, 2015).

Despite its contributions, agriculture alone cannot guarantee nutrition; factors like health services, sanitation, and child care practices also influence nutritional status. Intersectoral collaboration between agriculture, health, and education sectors is essential for sustainable improvements in nutrition (World Bank, 2015).

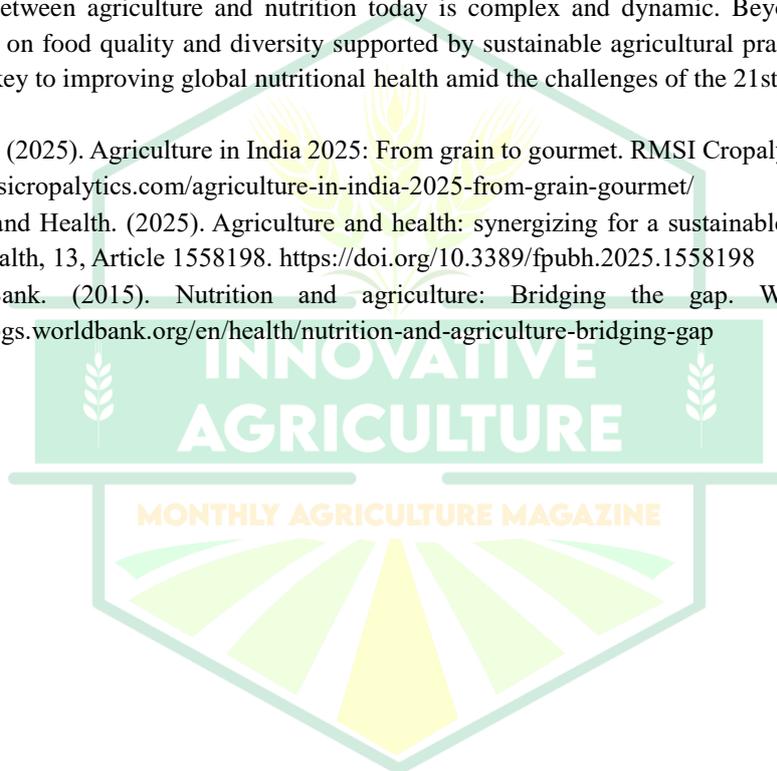
Recent global reports highlight that malnutrition remains a major cause of child mortality and lifelong developmental impairments, calling for intensified efforts to produce, process, store, and distribute nutritious food equitably. The economic value of the global food system is immense, but the related health costs from poor nutrition and unsustainable agricultural practices are significant and must be addressed (Farming and Health, 2025).

Conclusion

The relationship between agriculture and nutrition today is complex and dynamic. Beyond addressing food quantity, the focus on food quality and diversity supported by sustainable agricultural practices and integrated policies holds the key to improving global nutritional health amid the challenges of the 21st century.

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Conservation of Crop Diversity in India: Heritage and Future Imperatives



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Introduction

Seeds as stories – A seed is not merely a tiny speck of life; it represents a story waiting to unfold. Encased within its small shell are the memories of seasons gone by, the resilience of generations, and the promise of nourishment for the future. In India, where agriculture serves as both a livelihood and a cherished legacy, seeds are celebrated as symbols of continuity and hope. Farmers have cultivated a rich tapestry of crops that are uniquely adapted to their soils, climates, and cultural practices—from the terraced fields of the Northeast to the arid plains of Rajasthan. These seeds, often handed down through families or exchanged at village fairs, embody traits developed over centuries: drought tolerance, pest resistance, unique flavours, and medicinal benefits. They are living archives of biodiversity, shaped by the combined wisdom of nature and human experience. However, there is an opportunity to address the challenges facing these vital seeds. While industrial agriculture often emphasizes uniformity and speed, this shift has led to the decline of many traditional varieties. As climate change, market pressures, and habitat loss pose threats to our agricultural diversity, we have a chance to act. Conserving plant genetic resources is not just a scientific responsibility; it is a cultural and ecological imperative. By valuing and preserving crop diversity, we can ensure a sustainable future for our food systems. This article highlights India's rich agricultural heritage, the crucial role of gene banks in safeguarding this diversity, and the urgent need to revive and utilize these valuable resources for a climate-smart future. Together, we can cultivate resilience and foster a thriving agricultural landscape that honours the stories embedded in our seeds.

India: A crucible of crop diversity

India stands as a remarkable testament to agricultural richness. Celebrated as one of the world's foremost centers of crop origin and diversity, the country boasts an astonishing array of landraces, wild relatives, and traditional varieties meticulously adapted to its diverse soils, climates, and cultural practices. From the nutrient-packed desi chickpeas of central India to the fragrant basmati rice of the Indo-Gangetic plains and the resilient millets of the Deccan Plateau, India's fields are not just farms—they are dynamic laboratories of evolution. In the Eastern Ghats, tribal communities have preserved ancient varieties of kodo, little, and foxtail millets for generations. Meanwhile, in the high-altitude region of Ladakh, farmers cultivate cold-tolerant barley and peas that flourish under challenging conditions. This abundance is more than agricultural; it is a cultural heritage. Crops play a crucial role in shaping festivals, rituals, and regional cuisines. The revered status of rice in Tamil Nadu, the integral use of black gram in North Indian dals, and the healing attributes of moringa in traditional medicine all showcase how plant genetic resources are woven into the very fabric of identity and resilience. India's diverse agro-ecological zones—spanning from humid tropics to arid deserts—have fostered this extraordinary variety over centuries. Farmers, acting as guardians of biodiversity, have engaged in informal breeding through selection and seed exchange, preserving essential traits like drought tolerance, pest resistance, and nutritional richness long before modern science recognized their significance. Yet, this invaluable cradle of diversity faces urgent threats. Market-driven agriculture, habitat destruction, and the unpredictability of climate change jeopardize the very varieties that have historically sustained food and nutritional security. Acknowledging and conserving this genetic treasure is not merely an act of preserving the past; it is a vital investment in our future. Protecting this crop diversity is essential for ensuring food sovereignty, enhancing resilience to climate challenges, and promoting sustainable livelihoods for generations to come. Together, we must champion the cause of India's rich agricultural legacy for a thriving future.

Major challenges facing crop diversity in India

Monoculture dominance: The Green Revolution resulted in the extensive farming of high-yield rice and wheat varieties, which marginalized traditional crops such as millets, pulses, and oilseeds. This transition diminished genetic diversity and heightened susceptibility to pests, diseases, and climate-related stresses.

Market-driven crop choices: Farmers usually select their crops according to what the market wants and the minimum support prices (MSP), which tends to favour a small range of staple foods. The lack of financial motivation to grow a variety of crops or those that are less commonly used makes it hard to promote conservation on farms.

Climate change and abiotic stress: Unpredictable rainfall, increasing temperatures, and severe weather occurrences are changing agro-ecological zones. Numerous traditional varieties, despite their resilience, are still being neglected because of insufficient support or awareness.

Loss of traditional knowledge: Indigenous agricultural communities have historically maintained crop diversity by saving seeds and adapting locally. However, modernization and migration are undermining this knowledge, resulting in the loss of unique landraces specific to different regions.

Fragmented conservation efforts: While India has robust institutions like ICAR-NBPGR and the National Gene Bank, on-ground conservation is uneven. In situ conservation (on farms) is often neglected compared to ex situ (in gene banks), limiting dynamic evolution of traits.

Policy and institutional gaps: Crop diversification policies exist but are inconsistently implemented across states. Lack of integration between biodiversity conservation, agricultural extension, and rural development hampers impact.

Why conserving crop diversity for tomorrow matters?

In an era of climate uncertainty, nutritional challenges, and ecological stress, conserving crop diversity is no longer optional it is essential. The seeds we safeguard today will shape the resilience, health, and sustainability of agriculture tomorrow.

Adapting to Climate Change: Diverse crops offer a genetic toolkit to breed varieties that can withstand drought, heat, salinity, and erratic rainfall. For example, chickpea landraces with early maturity and heat tolerance are vital for future cropping systems in semi-arid regions.

Ensuring Food and Nutritional Security: Crop diversity supports dietary diversity. Traditional pulses, millets, and leafy greens are rich in protein, iron, zinc, and fiber. Conserving these crops helps combat hidden hunger and lifestyle diseases, especially in vulnerable populations.

Reducing Agricultural Risk: Genetic uniformity increases vulnerability to pests and diseases. Diversity acts as a buffer, reducing the risk of total crop failure. Wild relatives and landraces often carry resistance genes that can be introgressed into modern cultivars.

Empowering Breeding Innovation: Breeders rely on diverse germplasm to develop improved varieties with traits like yield stability, stress tolerance, and consumer appeal. Without conservation, the raw material for innovation dries up limiting our ability to respond to emerging challenges.

Preserving Cultural and Ecological Heritage: Traditional crops are deeply tied to local cuisines, farming practices, and festivals. Conserving them protects cultural identity. Many underutilized crops also support pollinators, soil health, and agro-ecological balance.

Building a Resilient Future: Gene banks, community seed banks, and on-farm conservation efforts are investments in agricultural resilience. Conserving crop diversity ensures we have choices not just for breeding, but for rebuilding systems aftershocks. In short, conserving crop diversity is about securing options for farmers, breeders, consumers, and ecosystems. It is a bridge between heritage and innovation, tradition, and transformation.

How India is responding and what we can do?

India is taking meaningful steps to conserve its crop diversity, but the journey is far from complete. Institutions, farmers, scientists, and citizens all have a role to play in safeguarding this living legacy.

Institutional Efforts: ICAR-NBPGR leads national efforts through the National Gene Bank, conserving over 450,000 accessions across crops. State agricultural universities and Krishi Vigyan Kendras (KVKs) promote on-

farm conservation and participatory breeding. Government schemes like the National Mission on Sustainable Agriculture (NMSA) and Millets Promotion initiatives support diversification.

Farmer-Led Conservation: Community seed banks and farmer cooperatives are reviving traditional varieties and sharing seeds locally. Participatory breeding programs empower farmers to select traits that matter most such as yield stability, taste, resilience.

Scientific Innovation: Researchers are characterizing germplasm for traits like drought tolerance, nutrient density, and pest resistance. Trait-based selection, especially in crops like chickpea, is guiding climate-smart breeding strategies.

What we Can Do?

We can choose diverse foods: Include traditional pulses, millets, and indigenous vegetables in our diet; Support seed savers: Buy from local farmers and cooperatives that conserve heirloom varieties; Raise awareness: Share stories of crop diversity in schools, communities, and social media; Engage with policy: Advocate for crop diversification, seed sovereignty, and agroecological farming. Conserving crop diversity is not just about preserving seeds but it is about protecting choices, cultures, and futures. Whether we are a scientist, farmer, policymaker, or consumer, our actions today can help sow resilience for generations to come. Conserving crop diversity is not just the job of scientists or gene banks. Consumers can support biodiversity by choosing traditional grains and pulses. Policymakers can incentivize conservation farming. Educators can integrate agro-biodiversity into curricula. And storytellers can amplify the message. India's plant genetic resources are more than scientific assets. They are cultural heritage, ecological insurance, and keys to future food security

Reviving diversity, reimagining agriculture: Fortunately, India is witnessing a quiet revival. Farmers are rediscovering traditional varieties. Participatory breeding programs are integrating indigenous knowledge with modern science. Crops like Kodo millet, once sidelined, are gaining popularity for their climate resilience and nutritional value. Trait prioritization - biochemical, physical, and functional is guiding smarter breeding strategies. By linking genetic variability to practical outcomes, we can develop cultivars that are not just high-yielding, but also climate-smart and culturally relevant.

Women: the silent custodians of seed diversity: In the serene corners of India's villages, women have quietly emerged as the heart and soul of agricultural biodiversity. These remarkable women dedicate their time and wisdom to selecting seeds after harvest and preserving them in earthen pots or cloth bundles, weaving a narrative of resilience that has shaped the genetic legacy of countless crop varieties. Their practices, lovingly handed down through generations, represent not just traditions but vital acts of conservation. With deep intuition, women farmers prioritize traits that often go unnoticed by commercial breeding, valuing taste, cooking quality, storability, and adaptability to local soils. Their thoughtful selections have given rise to resilient landraces of rice that flourish in flood-prone fields, pulses that swiftly mature in dry spells, and vegetables celebrated for their extraordinary flavor and nutrition. Today, we see community seed banks and women-led biodiversity groups in regions like Odisha, Uttarakhand, and the Deccan rising to prominence, recognized for their essential role in nurturing traditional varieties. These grassroots efforts beautifully complement the work of formal institutions like ICAR-NBPGR, creating a rich tapestry of conservation that blends scientific insight with the wisdom of lived experience. By empowering women as seed custodians, we not only protect invaluable genetic diversity but also honor a profound legacy filled with care, resilience, and ecological understanding. Their commitment reminds us of the vital connections between culture, community, and the environment, and the important role we all play in preserving our shared heritage.

Seeds of culture: Where biodiversity meets the kitchen: India's crop diversity is a remarkable treasure, intricately woven into the fabric of our culture and cuisine. Each region boasts heirloom varieties that carry unique stories, rituals, and flavors, reflecting its soil and heritage. The fragrant "Chakhao" black rice of Manipur, once reserved for royal feasts, and the iron-rich Kodo millet from tribal kitchens are just two examples of traditional crops that nourish both body and identity. These varieties are often central to festivals, like "Navadhanya" offerings during Navratri, or in ceremonial dishes that celebrate life's milestones. Culinary traditions have kept this diversity alive where formal systems may falter, with recipes passed down orally that maintain the use of indigenous legumes, leafy greens, and grains thriving without chemical inputs and adapting to local climates. By conserving crop genetic resources, we safeguard not just flavours and rituals, but also the very identities of our

communities. Every seed in the gene bank is more than just a genetic code; it embodies the potential for a climate-smart and vibrant future.

From field to genome: the digital revolution in crop diversity: The narrative of India's crop diversity is undergoing a remarkable transformation—it is evolving beyond seed vaults and field notes into a vibrant tapestry woven with technology, including advanced code, digital imagery, and DNA sequences. Breakthroughs in genomics, bioinformatics, and cutting-edge digital platforms are revolutionizing the way we conserve, characterize, and utilize our invaluable genetic resources. With high-throughput sequencing, researchers are now able to decode the genomes of landraces and wild relatives, unveiling essential traits like drought tolerance, disease resistance, and enhanced nutritional properties. These critical insights fast-track breeding programs, empowering scientists to identify the most promising crop accessions from the extensive collections housed in the National Gene Bank. Digital resources such as India's PGR Portal and international platforms like Genesys are making vital germplasm information accessible to breeders, researchers, and policymakers across the globe. Furthermore, the emergence of AI-powered tools is enhancing our capabilities in trait prediction, variability analysis, and automated descriptor scoring, infusing conservation science with unprecedented speed and precision. This innovative blend of tradition and technology not only ensures the preservation of India's genetic wealth but actively mobilizes it for sustainable, future-ready agriculture. We are witnessing a quiet revolution, where ancient seeds merge with modern algorithms to lay the groundwork for resilient food systems of tomorrow. The time is now to harness this potential and secure our agricultural future.

Reference: Various internet sources



Forensic Entomology: When Insects Speak for Justice



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Abstract

Forensic entomology involves the application of insects and other arthropods and their living stages found on the decaying remains for criminal investigations. By identifying the specific species of insect and its life stage, the postmortem interval (PMI) can be assessed and also the approximate time of death can be estimated. It not only provides light on when the incident happened, but also how, if the use of drugs and poison is involved in the crime. As the stage of decomposition varies with time, the types of insects visiting also varies. Today forensic entomology has also its application on cases involving drug trafficking and wildlife hunting.

Keywords : Forensic entomology, insects, postmortem interval

Introduction

Insects have always known as nuisance in agriculture, public health, household etc destroying crops and transmitting diseases eventhough many are beneficial as pollinators, scavengers and productive like honeybees, lac insect etc. Regardless of all these facts many don't know that these tiny beings play a crucial role in forensic science solving serious criminal cases. Forensic entomology is the study of insects or other arthropods involving legal matters and criminal investigations. Although the application of insects and arthropods in criminal investigation are employed since ages, the application of forensic entomology have become broad involving its application in narcotics and illegal wildlife hunting due to advance in technology.

History

The first record of application of insects in solving a murder case is shown in the book "The Washing Away of the Wrongs: Forensic Medicine in the Thirteenth- century China" by Sung T'zu in 1247 where the suspect of a murder case confessed after interrogation when the suspected murder weapon attracted blowflies probably due to blood tissues present on it. In 1850, the French courtroom witnessed the application of forensic entomology for the first time to prove the innocence of the suspects in case of a child murder case- reported by Bergeret.

What happens after death...?

We all know that various tissues in our body dies at various rates. After an cardiac arrest, the brain dies within minutes due to oxygen deprivation. After death, the microbes in the intestine like the bacteria and protozoa become active and decomposition starts. Putrefaction of the body starts and gases starts to accumulate, bloating the body emitting a putrid odour. This smell attracts various insects where the blow flies and flesh flies of the family Calliphoridae and Sarcophagidae are the initial visitors.

The types of species found

According to Smith (1986), there are four categories of insect fauna that appear on the mortal remains.

1. Necrophagous insects : that feed on dead remains
2. Predators and parasites : that feed on necrophagous insects feeding the carrion
3. Omnivorous insects : insects that feed both on carrion and other insects on it (ants, wasps etc.)
4. Springtails and spiders : use the carcass as an extension of their environment

Estimation of time of death

Forensic pathologists helps to estimate the time of death based on the temperature of the cadaver and rigor mortis if the corpse is not old beyond three days. After death the temperature starts to drop and and the muscles become stiff due to lactic acid accumulation called rigor mortis. The role of forensic entomologists become crucial when the body is older than three days. Here based on the entomofauna present on the cadaver and the stage of the specific insect species present, the time of death is approximately estimated.

Postmortem Interval (PMI) : It is the time interval between the death and the discovery of a corpse. It is estimated by identifying the specific species of insect feeding on the remains and its life stage. By knowing its lifecycle the

forensic entomologists can assess the age of living stage of the insect and through that the PMI. As insects are poikilothermic, the temperature difference affects the fly development. In warmer areas the development of insect will be faster and in colder areas it slows down.

Stages of decomposition and the fauna found in each stages

Fresh stage : Stage from death till bloating become evident. The first to appear on this stage is the Calliphorids (blow flies).

Bloated stage : Intestinal microfauna become active and starts decomposition. The body putrefies and the corpse bloats due to generation of gases like methane inside the body. More flesh flies and blow flies are attracted due to the odour emitted. Beetles like Histerids and Staphylinids are also attracted to it for preying the fly larvae.

Active decay stage : The body ruptures causing the gases to escape while putrefaction goes on. Insects like Clerids, Dermestids, Histerids, Staphylinids etc. are seen.

Post decay stage : In this stage there is an increase in the number of beetles and its other life stages while maggot population decrease drastically.

Skeletonization : Since all body tissues are decomposed, only bones and hair will be remaining during this stage. Insects that can decompose keratin will be present like the Clerids and Dermestids.

Not just the question of when...but also how....

With the recent advances in forensic entomology, the investigators can not only determine the time of death but also the cause of death in case of use of drugs or poison prior to the death. In many a time, blood, urine or tissue sampling can be done but not in the case of a body which is days old. In this case, the sampling can be done from the maggots or the pupa found on the cadaver. The chemicals like cocaine, heroin, malathion, mercury, phenobarbital etc. can be traced from maggots. Also some chemicals can alter the rate of development of insects developing on the cadaver affecting the estimation of Postmortem Interval.

Other Applications

Forensic entomology also has its application in drug trafficking and illegal wildlife hunting and poaching. Often in case of drug trafficking, the drugs would be traded in one region and produced in another. By analyzing the insect fauna found on the drugs and mapping its geographical distribution the place where the drug was produced can be traced. Also in case of illegal hunting of wildlife, the postmortem interval can be estimated based on the entomofauna present and its life stage.

Conclusion

Forensic entomology draws on the silent testimony of insects found on the corpse, offering critical hints to solve complex cases. It demonstrates the vital role of nature in bringing the culprits to justice. Many a time the evidence become inadequate, these tiny creatures pave the way for solving the mystery. As the science continues to grow, its applications are also widening. Although the procedure involves serious expertise and procedure, it still serves as a vital tool with endless possibilities.

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Probiotics and Prebiotics by Granny



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During my childhood whenever I suffer from the most common digestive disturbance – diarrhea – the first home remedy offered by my mother was, flame cooked plantain (green banana or vegetable banana) along with a cup of sour curd. It worked, wonderfully, in less than a day. Later my mother informed she learnt that combination from her grandmother during pre-1970 period. The same remedy is working still, even for my children. My memories of this therapeutic diet are so fresh, owing to the frequency of stomach upset during my childhood, because of sweets sold in streets, with free access to files – files with round the clock access to drainage. Obvious was the status of open air defecation in rural India three decades ago.

Back to home remedy, immediately after noticing the first symptom, my mother used to starve us from routine food immediately. Then she used to keep a plantain on charcoal chullah, rotating it for uniform heat treatment, till all the outer peel became coal-black in color. Upon gentle rubbing by finger, the charred coat would shed as black powder, exposing white and well-cooked inner pulp with steam fumes of a pleasant flavor. This diet therapy is still effective in my home, even after my wife took over kitchen, even to my children since the age of a year. We visit the doctor only after administering this diet and allowing it 6-8 hours to work. Even if it failed; this supplement would be additional to the doctor's prescription. I am more than convinced about its effectiveness. The modern education thought us to evaluate our elders' wisdom as directly proportional to their formal school education. My mother is 8th class pass-out and grandmothers are even less-educated – as per this stereotypic yardstick. So, after graduating in Veterinary Medicine and specializing in the subject of nutrition, having acquired relevant knowledge in biochemistry, microbiology physiology etc etc, I evaluated this diet with my modern knowledge – not because of my respect to the elders, just because it worked and is working. So, I checked the scientific rationale of this combination, with the help of my colleague who coauthored this article.

Curd is a rich source of nutrients, needless to say. Besides being nutritious, it contains highest number of bacteria – yes, bacteria, but useful bacteria. The bacteria belonging to species *Lactobacillus* (Plural – *Lactobacilli*). It is the same type of bacteria available in capsules widely prescribed by physicians, especially the gastroenterologists in human medicine. The technical name of these bacteria is Probiotics. How these bacteria are useful? They are useful in more than one way:

1. Forming a protective layer on inner wall of intestines (mucosa), and preventing pathogenic bacteria from entry.
2. Displacement of already existing pathogenic bacteria from the intestinal mucosa.
3. Production of substances which are toxic to pathogenic bacteria, but not toxic, rather useful to the host animal/human.
4. Improving micronutrient absorption by the host.
5. Modulation of intestinal immunity. When lactobacilli are sensed on the intestinal wall, the body immune system responds by assuming that these probiotic bacteria as enemies, and deploys more white blood cells in the intestinal tissue, without real combat between the WBC and bacteria. It is because the lactobacilli never cross the line. The situation is like a continuous mock-drill on both sides of a war-prone border. So, when pathogenic bacteria, if at all gain entry by escaping the probiotic layer, will be neutralized by the heavily deployed white blood cells (WBC) of body. Research had proven that in the absence of probiotic layer, WBC number in the intestinal tissue is bare minimum.

We are convinced about role of curd in curing. What role the flame cooked plantain plays? Banana (When consumed as ripened fruit) is source of carbohydrates. Carbohydrates means a large group of nutrients with different degree of digestibility and energy value. Sugars are the simplest carbohydrates, with easiest digestibility and high energy value. Starch is the most common carbohydrate of foods. Fiber is also a type of carbohydrate,

with zero digestibility by any animal's own digestive system. Fiber is widely found in leaves, stems, stalks of green leafy vegetables and peels fruits and vegetables. But fiber is scanty in pulp of fruits and vegetables. In granny's therapeutic diet, the fiber content is negligible. There is another group of carbohydrates called as Non Starch Polysaccharides (NSP). Chemically these are Fructo Oligo Saccharides (FOS) and Mano Oligo Saccharides (MOS). Both FOS and MOS are widely found in pharma products and prescribed along with Probiotics. These NSP substances are not available for digestion, so they are available to the intestinal microbes. Lactobacilli are known to proliferate rapidly on these NSP substances. Since they multiply probiotic population, they are called as Prebiotics. Plantain is a rich source of NSPs. With ripening, the NSP content reduces, because the NSP undergo hydrolysis and transform into sugars. Besides NSP, plantain also contains tannins, which have coating and smoothening effect on micro ulcers of intestines during bowel upset.

When curd contains trillions of lactobacilli, why should we supplement with prebiotics? Reason being, whatever we consume as food, had to pass through stomach, where more than 99% of microbes are killed because of hydrochloric acid secreted in stomach, as gastric juice. Gastric juice doesn't discriminate useful and harmful bacteria. Hence, lactobacilli consumed in food are no exception. That's why the pharma industry packs lactobacilli in gelatin capsules protecting them from gastric juice. Our grannies preferred curd, through which, even after 99.9% killing in gastric juice, a million bacteria would escape out of the trillion consumed. In order to make their numbers again, the natural prebiotic does the remaining job. Granny's therapeutic diet is neither inferior nor unscientific. Its only weakness is that, she never bothered to know modern medical terminology like Physiology, Biochemistry, Microbiology, Probiotics, Prebiotics etc., and also was least bothered to document her wisdom or getting accepted by Scientific Community.

This therapeutic diet provides ample of scope for modern clinical nutritionists. It could be as useful as ORS (oral rehydration solution) in reducing child mortality arising from monsoon diarrheas of rural India and urban slums.



Soil Ecosystem Services and Nutrient Management Systems for Rice A Farmer-Focused Guide to Soil Stewardship



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Abstract

Soil provides essential ecosystem services that sustain rice cultivation — from nutrient cycling and water regulation to supporting biodiversity and carbon storage. This popular article explains how different nutrient management systems (chemical, organic, and integrated) influence those services, and presents practical, farmer-friendly actions that strengthen soil health and long-term yields. The article emphasizes stewardship: simple, cost-effective practices rice farmers can adopt to improve soil fertility, reduce losses, and make their fields more resilient to climate variability. The Indian context is highlighted with data on rice area, production, and productivity, along with the nutrient budgets and threats to soil ecosystem services.

Introduction

Rice is the backbone of India's food security, providing the staple diet for more than half of the population. With nearly 43–44 million hectares under cultivation and an annual production of about 125–135 million tonnes, rice farming supports millions of smallholders. The national average productivity is about 3.0–3.1 t ha⁻¹, but yields vary widely — from less than 2 t ha⁻¹ in rainfed eastern states to over 5 t ha⁻¹ in irrigated systems of Punjab, Haryana, and parts of Andhra Pradesh and Tamil Nadu. These differences reflect not only water availability and varieties but also soil fertility management and the health of soil ecosystem services. However, the push for higher yields has placed unprecedented pressure on soil resources. Over-reliance on chemical fertilizers, residue removal or burning, and continuous monocropping have led to nutrient imbalances, declining soil organic carbon, and reduced soil biodiversity. Understanding soil as a provider of ecosystem services — nutrient cycling, water regulation, biodiversity support, and carbon storage — is essential for ensuring that rice production remains both profitable and sustainable.

Soil ecosystem services under pressure in rice fields

While rice fields deliver food security, intensive cultivation often reduces key soil ecosystem services. Heavy reliance on chemical fertilizers without replenishing organic matter leads to nutrient imbalances and declining soil organic carbon. Continuous flooding reduces soil structure and drainage, sometimes resulting in hardpans. Monocropping and pesticide overuse suppress microbial populations, earthworms, and natural nutrient transformers. Residue burning and lack of organic inputs reduce soil carbon stocks.

Nutrient removal in rice systems — what soils give away

Every tonne of rice grain and its associated straw remove significant nutrients from the soil. On average, nitrogen removal is 18–25 kg per tonne of grain, phosphorus (P₂O₅) removal is 6–8 kg, and potassium (K₂O) removal is 25–35 kg. Sulphur removal ranges from 2–4 kg per tonne, while micronutrient removal includes 100–300 g of zinc, 0.5–1.0 kg of iron, 0.3–0.6 kg of manganese, and 20–50 g of copper per tonne of grain. Where residues are removed or burnt, these nutrient losses are even higher, compounding the strain on soil nutrient pools.

Nutrient budgets under different rice cultivation systems

Nutrient budgeting compares nutrient inputs (fertilizer, manure, deposition, biological fixation) with outputs (harvested grain, straw, leaching, gaseous losses). In India, nutrient budgets show both positive and negative balances depending on the system. In high-input irrigated rice, nitrogen and phosphorus budgets are often positive due to heavy fertilizer use, but potassium budgets are usually negative because K application rarely matches crop removal. In rainfed low-input rice, the budgets for all primary nutrients — N, P, and K — are negative, indicating nutrient mining and long-term soil degradation. In organic rice systems, N and P budgets can be negative unless sufficient manure or green manures are applied, while K balances may remain neutral or positive if crop residues are recycled. In integrated nutrient management (INM) systems, N and P budgets are generally balanced or slightly positive, while K balance improves when organic inputs are included. These imbalances pose clear

threats: positive budgets lead to nutrient losses and pollution through runoff and gaseous emissions, while negative budgets deplete soil nutrient reserves, undermining soil fertility and ecosystem services.

What nutrient management systems do — and why they matter for soil services

Chemical or inorganic fertilizers deliver nutrients quickly and reliably, boosting yields in the short term but harming soil life and increasing nutrient losses if used excessively or poorly timed. Organic sources such as compost, farmyard manure, and green manures build soil organic matter, feed the soil biota, and gradually improve water-holding capacity and nutrient retention, but their nutrient release is slower and variable. Integrated Nutrient Management (INM) combines both, aiming to deliver crop demand while rebuilding soil health.

Table 1 — Comparison of common nutrient management systems for rice

Nutrient System	Short-term yield response	Effect on soil organic matter	Effect on nutrient losses (leaching/denitrification)	Labour & management	Best for
Chemical fertilizers (high input)	High and rapid	Neutral to negative if residues removed	Higher if over-applied or poorly timed	Lower labour for sourcing/applying ; requires good timing	Farmers needing rapid response or where manure is scarce
Organic amendments (FYM, compost, green manures)	Moderate, slow-release	Improves — builds SOC and structure	Lower (better retention) but may release N slowly	Higher labour for production/handling	Long-term soil rebuilding, smallholders with organic resources
Integrated Nutrient Management (INM)	High with sustained gains	Maintains / increases SOC over time	Lower than chemical-only when managed	Moderate — needs planning and monitoring	Farmers seeking balance between yield & sustainability

Practical soil stewardship: steps farmers can take today

Soil stewardship means managing fields so the soil's services keep working for you and future generations. Farmers can match fertilizer to crop needs by applying the right rate at the right time and place, using nutrient budgeting or simple field-level indicators such as leaf colour charts and plant height to avoid over- or under-application. Keeping a continuous cover by retaining straw or sowing a cover or green manure after harvest protects soil from erosion and feeds soil life. Recycling farm residues by composting straw, weeds, and fodder residues helps maintain organic matter. Using split applications for nitrogen at transplanting, tillering, and panicle initiation matches uptake and reduces losses in heavy rains. Adopting alternate wetting and drying (AWD) where suitable reduces methane emissions, saves water, and reduces N losses when combined with good N timing. Testing soil periodically informs lime and fertilizer needs and avoids waste. Protecting and encouraging soil life by avoiding excessive pesticide use and favouring practices that build earthworms and microbes also strengthens soil fertility.

Table 2 — On-farm stewardship actions and typical benefits for rice farmers

Stewardship action	When farmer may notice benefits	Typical farmer-observed benefits
Split N applications (3–4 splits)	Within the same season	Better grain filling, reduced fertilizer waste, fewer lodging problems after heavy rain
Applying compost or FYM (every season or alternate seasons)	1–3 seasons	Improved soil tilth, better water retention, reduced need for frequent irrigations
Retaining/residue management (mulch or composting straw)	Within 1 season to 2 years	Cooler soil in hot spells, improved seedling establishment, reduced erosion
Alternate wetting and drying (AWD) + careful N timing	Same season	Lower water usage, sometimes higher profits due to lower water cost and reduced methane emissions
Small-scale green manures or legume cover crops	1–2 seasons	Increased soil N, improved structure, more earthworms and natural pest checks

Farmers' knowledge and local adaptation: the key to success

There is no single best system for all farms. The most successful farmers adapt principles — match nutrients to needs, build organic matter, and protect soil life — to local soils, water availability, labour constraints, and market forces. Farmer field schools, local trials, and peer-to-peer learning help discover what works in each village.

Economics: stewardship pays off

While some stewardship practices require labour or time such as making compost or planting cover crops, they often lower long-term input costs, reduce risk from climate shocks, and stabilize yields. Integrated nutrient management presents the best economic balance by maintaining yields while gradually restoring soil productivity.

A short roadmap for extension workers and local leaders

Extension workers and local leaders can play an important role by demonstrating simple techniques in farmers' fields, such as split nitrogen applications, residue composting, and AWD. Encouraging low-cost soil testing and the use of leaf colour charts helps optimize fertilizer use. Promoting farmer-to-farmer learning and co-creation of compost recipes supports low-cost solutions. Incentivizing practices that store carbon and reduce emissions helps align farm management with environmental goals.

Conclusion

Rice cultivation in India is at a crossroads: the demand for higher production continues to grow, yet the soil resources that underpin productivity are being strained. Nutrient budgets show clear evidence of imbalance — nutrient mining in rainfed systems, nutrient surpluses and losses in irrigated systems, and inconsistent nutrient supply in organic systems. These threaten the soil's ability to provide vital ecosystem services. By adopting integrated nutrient management and soil stewardship practices, farmers can restore balance, reduce losses, and safeguard their soils for future generations. Building organic matter, recycling residues, and applying fertilizers with precision are essential investments in the sustainability of India's rice-based farming systems.



The Silent Revolution Beneath Our Feet: Harnessing Regenerative Agriculture for a Food-Secure Future



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Introduction:

The Cracks in the Modern Field For the past century, the story of global agriculture has been one of incredible triumph. The Green Revolution, with its high-yield crop varieties, synthetic fertilizers, and chemical pesticides, saved millions from starvation and enabled the growth of our modern world. It was a testament to human ingenuity. However, this intensive, industrial model of farming, focused almost exclusively on yield, has come at a significant cost. Today, we see the cracks forming in this foundation. Our soils are degrading at an alarming rate, biodiversity is plummeting, freshwater resources are strained, and agriculture has become a major contributor to greenhouse gas emissions. The very system designed to feed humanity is now facing a crisis of sustainability. Farmers are caught in a cycle of dependency on costly external inputs, their fields are less resilient to the increasing volatility of our climate—be it prolonged droughts or intense flooding—and the nutritional value of our food is, in some cases, declining. We have pushed our natural systems to their breaking point.

But what if we could change the narrative? What if, instead of simply extracting from the soil, we could partner with nature to rebuild it? This is the promise of a powerful and growing movement in agriculture, a "silent revolution" that starts from the ground up: Regenerative Agriculture. This is not a return to antiquated methods but a sophisticated, science-informed approach that views farms not as factories, but as vibrant, living ecosystems. It offers a pathway to not only produce abundant, nutritious food but also to restore our landscapes, sequester carbon, and build a truly resilient food system for generations to come.

What is Regenerative Agriculture? A Paradigm Shift At its heart, regenerative agriculture is a holistic land management philosophy that seeks to improve the health of the entire farm ecosystem, with a primary focus on the soil. Think of soil organic matter—the rich, dark, carbon-based component of healthy soil—as a bank account. For decades, industrial agriculture has been making massive withdrawals from this account. Regenerative agriculture is the strategy for making consistent deposits, rebuilding that natural capital.

This approach is guided by a set of core principles rather than a rigid set of rules, allowing farmers to adapt practices to their unique local conditions. The key principles are: Minimize Soil Disturbance: Tillage, or ploughing, is like an earthquake for the soil's microscopic ecosystem. It breaks up soil structure, kills beneficial fungi and bacteria, and releases stored carbon into the atmosphere. This principle advocates for reducing or eliminating tillage.

Maximize Crop Diversity: Monoculture (planting the same crop year after year) is fragile and depletes specific nutrients. Nature thrives on diversity. Planting a variety of crops in rotation, or even together, breaks pest cycles, improves nutrient cycling, and creates a more resilient system.

Keep the Soil Covered: Bare soil is vulnerable. It is easily eroded by wind and water, loses moisture to evaporation, and cannot support the life within it. This principle emphasizes the use of cover crops or mulch to keep the soil protected at all times, like a living skin.

Maintain Living Roots Year-Round: The continuous presence of living roots in the soil feeds the vast underground ecosystem of microbes (the soil microbiome). These microbes, in turn, make nutrients available to the plants. It's a symbiotic relationship that powers the entire system.

Integrate Livestock: In natural ecosystems, animals play a crucial role. Managed grazing, where animals are moved strategically across pastures, can stimulate plant growth, add fertility through manure, and help manage

vegetation without chemicals. When these principles are applied together, they create a virtuous cycle. Healthier soil grows healthier plants, which are more resistant to pests and diseases, reducing the need for chemical inputs. This healthier soil also acts like a sponge, absorbing and holding rainwater far more effectively, making farms more resilient to drought. Most excitingly, this process draws enormous amounts of carbon dioxide out of the atmosphere and stores it securely in the soil, transforming farms from carbon sources into powerful carbon sinks.

Specific Recommendations: Putting Principles into Practice. Transitioning to regenerative practices requires knowledge and intention. Here are specific, actionable recommendations for farmers looking to embark on this journey.

Recommendation 1: Adopt No-Till or Conservation Tillage

This is the cornerstone of minimizing soil disturbance.

What It Is: Instead of ploughing the entire field, farmers use specialized seed drills that cut a small slit in the soil, drop in the seed and fertilizer, and close the slit, leaving the rest of the soil and previous crop residue undisturbed.

How to Start: Begin on a small, manageable plot of land to learn the technique. Invest in or rent a no-till seed drill. In India, the "Happy Seeder" is a fantastic example of technology adapted for no-till rice-wheat systems.

Key Benefits: Dramatically reduces soil erosion, conserves soil moisture (reducing irrigation needs by up to 30%), lowers fuel and labor costs, and allows the soil's biological community to rebuild. The residue left on the surface acts as a natural mulch.

Recommendation 2: Implement Intelligent Cover Cropping and Intercropping

This directly addresses the principles of keeping soil covered, maintaining living roots, and maximizing diversity.

What It Is:

Cover Cropping: Planting a specific crop, like lentils, mustard, or clover, not for harvest, but to cover the soil between main cash crop seasons.

Intercropping: Growing two or more different crops together in the same field at the same time. A classic example is the "three sisters" system of maize, beans, and squash.

How to Start:

For Cover Crops: After harvesting your main crop (e.g., rice), broadcast seeds of a fast-growing legume like dhaincha (*Sesbania*).

It will fix nitrogen, suppress weeds, and can be rolled down to form a nutrient-rich mulch for the next crop (e.g., wheat).

For Inter cropping: In a sugarcane field, plant rows of mung beans or chickpeas in between the cane rows. The legumes will fix nitrogen that benefits the sugarcane, provide a second source of income, and cover the soil.

Key Benefits: Suppresses weeds naturally, reduces the need for nitrogen fertilizer (if using legumes), improves soil structure with diverse root systems, attracts beneficial insects, and provides an additional source of income or animal fodder.

Key hurdles include:

Knowledge Gap: Decades of industrial agriculture have eroded traditional and ecological farming knowledge.

Transition Period Risks: There can be a temporary dip in yields for the first 1-3 years as the soil biology begins to recover.

Economic Barriers: Initial investments in new equipment (like a no-till drill) or the perceived risk of trying something new can be daunting for smallholder farmers.

Policy and Market Misalignment: Government subsidies often favor synthetic inputs, and the market doesn't typically pay a premium for food grown regeneratively (though this is slowly changing).

Addressing these requires a concerted effort. Governments can shift subsidies from chemical inputs to supporting regenerative transitions, funding farmer training programs, and creating crop insurance products that reward soil health improvements. Researchers must work alongside farmers to develop locally-adapted regenerative systems. Consumers can play a role by supporting brands and farmers who are committed to soil health. Farmer-to-farmer knowledge networks are perhaps the most powerful tool, allowing practitioners to share successes and failures, building confidence and community.

Conclusion:

Seeding a Resilient Future: Regenerative agriculture is more than just a set of techniques; it is a fundamental rethinking of our relationship with the land. It asks us to see our farms as complex, living systems with the potential for self-renewal. The challenges we face—climate change, food insecurity, environmental degradation—are immense, but the solutions are literally under our feet. By minimizing disturbance, diversifying our fields, keeping the soil covered, and reintegrating plants and animals, we can build a food system that is not only productive but also restorative. It is a path that offers greater economic stability for farmers, more nutritious food for communities, and a healthier planet for us all. The silent revolution is happening, one field at a time. The time to listen to the soil and join in is now.



Understanding the Ecological and Nutritional Benefits of Natural Farming in Vegetable Cultivation



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Introduction

Natural Farming is a chemical-free farming system rooted in Indian tradition enriched with modern understanding of ecology, resource recycling and on-farm resource optimization. Natural Farming also known as 'the Fukuoka Method' or 'do nothing farming' which is an ecological farming approach established by Masanobu Fukuoka (Fukuoka, 1978). There is another term used in natural farming that is Zero Budget Natural Farming (ZBNF) which is a sustainable method of farming practices which do not involve use of any artificial fertilizers and pesticides that ensures the healthy growth and improved soil fertility (Kumar Das, et. al. 2022). There are several steps involved in natural farming from 1 to 3 years of agricultural land conversion period, farm designing, choice of varieties of crops, land management, nutrient management, weed management to soil and water conservation (De, 2022). From the Nutritional standpoint naturally grown vegetables provides rich sources of micronutrients including sodium, potassium, zinc, manganese, calcium, Iron, vitamin A, Vitamin C, as well as phyto-nutrients such as phenolic compounds, terpenoids and hence can be used as therapeutic dietary formula (Acharya and Kendra, 2013). Vegetables form the backbone of human diets, providing essential vitamins, minerals, and fiber needed for growth and health. However, the way vegetables are cultivated greatly influences not only their nutritional content but also the health of the environment and farming communities. Conventional farming, heavily dependent on synthetic fertilizers, pesticides, and intensive irrigation, has raised concerns related to soil degradation, biodiversity loss, and chemical contamination of food. In contrast, natural farming has emerged as a promising alternative that help to ensure the production of safe and nutrient-rich food.

Principles of Natural Farming

In Natural Farming there is no weeding, no tillage, no pesticides and herbicides, no fertilizers and no pruning is carried out just as it would in ecosystems found in nature (Kaur, 2020). Among the four, the first is No Tillage, that is no plowing or turning of the soil. For centuries, farmers have assumed that the plow is essential for growing crops. However, non-tillage is fundamental to natural farming. The earth cultivates itself naturally by means of the penetration of plant roots and the activity of microorganisms, small animals, and earthworms. The second one is called Chemical-Free Fertilizer. Their sloppy agricultural methods deplete the soil of vital nutrients, which causes annual land depletion. If the soil is left alone, it will naturally maintain its fertility in accordance with the regular cycle of plant and animal life. The third Principle is No

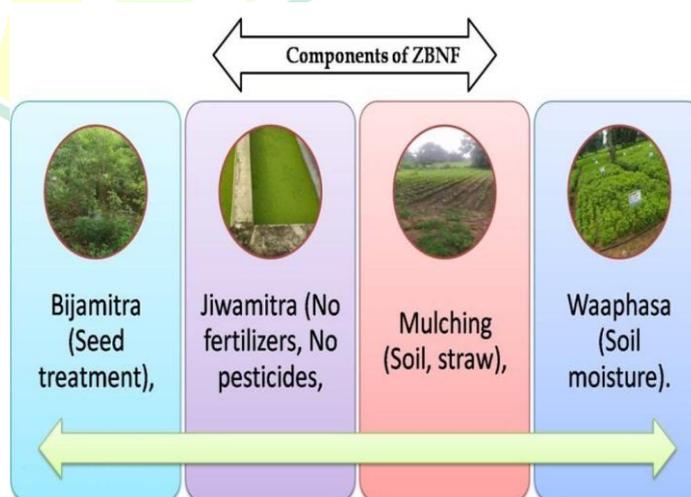


Figure1: Different components of Zero Budget Natural Farming

Weeding or use of Herbicides. In India, Zero Budget Natural Farming (ZBNF), pioneered by Subhash Palekar, is a prominent model. It involves the use of simple, locally available inputs like Jeevamrit (a microbial solution made from cow dung, cow urine, and pulse flour), Beejamrit (seed treatment solution), mulching, crop diversification, and intercropping.

Ecological Benefits of Natural Farming in Vegetable Cultivation

1. Soil Health Restoration

The soil health is pivotal for sustainable and regenerative agriculture namely natural farming. It emerges as a holistic approach that encourages diverse plant communities and microorganisms enhances soil structure, nutrient cycling, and water retention etc through the application of various soil health based inputs. It boosts farmers' income while restoring soil fertility, aiding to reduce greenhouse gases and provide ecosystem services. Hence, the soil health management through natural farming emerges as a unifying solution. Soil health most often refers to the “ability of the soil to sustain agricultural productivity and protect environmental resources”. A healthy soil provides many functions that support plant growth of vegetable, including nutrient cycling, protect the soil from erosion, biological control of plant pests, and enhances water holding capacity and drainage. These functions are influenced by the interrelated physical, chemical, and biological properties of soil, many of which are sensitive to soil management practices. In natural farming, soil health is maintained through the four foundational practices e.g. **Whapasa, mulching, Jeevamrit, and Beejamrit**, which collectively enhance the physical, chemical, and biological properties of the soil. These practices improve moisture retention, minimize soil erosion, and foster a diverse and active microbial community, thereby ensuring long-term soil fertility and resilience.

2. Environmental Benefits

Natural farming provides numerous environmental benefits, ranging from reducing exposure to harmful chemicals to mitigating the effects of global warming. In contrast, conventional agriculture relies on synthetic chemicals that contribute to soil erosion and negatively impact the environment, whereas natural farming avoids chemical fertilizers and there by supports the preservation of the natural ecosystem. Several researches have shown that natural farming has eliminate about 500 million pounds of pesticides and chemicals from entering into the environment (Economic and Political Weekly, 2019). On an average, natural farming uses 30 to 50 per cent less energy than conventional farming. Natural farming does not involve use of synthetic nitrogen-based chemicals and thus reduces nitrogen run-off induced pollution (Government of India, 2001). This type of farming practices also facilitates the healthy soil formation due to its entire cultivation process and by balancing its carbon and nitrogen cycle. Another impact of natural farming combats the effect of global warming as it is a sustainable practice that potentially reduces the carbon-dioxide production. By these ways the natural farming protects our environment and increases sustainability (Kumar et. al 2020).

3. Health Benefits

Vegetables cultivated under natural farming systems are recognized for their superior health-promoting qualities compared to conventionally grown produce. The absence of synthetic fertilizers and pesticides ensures that these vegetables are free from harmful chemical residues, thereby reducing risks associated with endocrine disruption, neurological disorders, and cancers. Moreover, naturally grown vegetables are richer in essential vitamins, minerals, and antioxidants which play a vital role in boosting immunity, protecting against oxidative stress, and lowering the incidence of chronic diseases including cardiovascular ailments, diabetes, and neurodegenerative conditions (Baranski et al., 2014; Yu et al., 2018). The improved nutritional profile, combined with chemical safety, makes naturally cultivated vegetables particularly beneficial for vulnerable populations such as children, pregnant women, and the elderly. In this way, natural farming contributes directly to public health by ensuring the availability of clean, nutrient-dense, and therapeutic food sources.

Nutritional Benefits of Natural Farming in Vegetable Cultivation

1. Enhanced Nutrient Density

Several researches suggested that vegetables grown by natural farming are more nutritious when compared to the vegetable obtained by conventional farming. Chemical fertilizers used in conventional methods makes the soil deficient in essential micronutrients such as zinc, iron, maganese (Agarwal and Gupta, 2020). In the natural farming small to moderate increase in antioxidants have been shown such as flavonoids, isoflavonols, anthocyanins, carotenoids, polyphenols, which help significantly in increasing immunity, eliminate free radicals

from the body and also acts as an anticancer agent. They also provide skin protection, bright eyes, and prevent osteoporosis (Yu et al. 2018). These compounds also have been found to protect against chronic diseases including cardiovascular disease, and neurodegenerative diseases (Baranski et al. 2014). The livestock or farm animal require more omega-3 fatty acids and includes feeding cattle grass and alfalfa. Omega-3 fatty acids are proved to be cardio friendly and found in organic meats, dairy and eggs (Ryan, 2004). Cadmium is a toxic chemical naturally found in the soils and absorbed by plants; studies have shown that low cadmium level was found in foods that grown by natural farming due to ban on synthetic fertilizers. Meat produced by natural farming shown to contain low level of hazardous bacteria (Mayoclinic, 2021). Naturally grown foods are found to be higher in potassium, phosphorus, magnesium, iron and calcium when compared to conventional practices. Heavy metals used in chemical intensive farming can harm the nervous system, infertility and cancer. As for example potassium is used as chemical fertilizer which decreases the absorption of magnesium in plants (Yu et al. 2018).

2. Absence of Chemical Residues

A major nutritional and health-related benefit of natural farming in vegetable production is the lack of toxic chemical residues. Traditional agricultural methods depend significantly on artificial pesticides, herbicides, and fertilizers, which frequently leave visible residues on crops even post-harvest and washing. Prolonged intake of these residues has been linked to endocrine disruption, issues with reproductive health, neurological conditions, and a higher likelihood of developing some cancers (Aktar et al., 2009). Conversely, natural farming methods ban synthetic agrochemicals and instead utilize botanical extracts, bio-fertilizers, and ecological pest control techniques, which significantly lessen the amount of harmful contaminants in vegetables. Research has demonstrated that vegetables grown by natural farming environments consistently exhibit lower or minimal pesticide residue levels compared to those produced conventionally (Baranski et al., 2014). Furthermore, minimizing exposure to toxic chemicals not only guarantees safer food for consumers but also enhances dietary quality. Consequently, the lack of chemical residues in naturally grown vegetables improves their safety standards and establishes natural farming as an essential method for maintaining long-term public health safety

3. Improved Taste and Shelf Life

Vegetables produced under natural farming systems are frequently reported to possess superior sensory qualities and extended shelf life when compared with conventionally cultivated counterparts. The improved taste of naturally grown vegetables is largely attributed to the balanced uptake of minerals and the higher concentration of secondary metabolites such as sugars, organic acids, and phenolic compounds, which influence flavor, aroma, and texture (Reganold and Wachter, 2016). By avoiding synthetic fertilizers, which often promote rapid but less nutrient-dense growth, natural farming ensures a slower and more balanced nutrient assimilation that enhances the intrinsic taste profile of vegetables. In addition, the higher antioxidant content and stronger cell wall structures of naturally grown vegetables contribute to delayed post-harvest senescence, thereby increasing their shelf life (Baranski et al., 2014).

4. Contribution to Human Health

Vegetables cultivated under natural farming systems make a significant contribution to human health by providing nutrient-dense, chemical-free, and antioxidant-rich food. The higher concentrations of essential vitamins, minerals, and bioactive compounds such as flavonoids and carotenoids strengthen the immune system, protect against oxidative stress, and lower the risk of chronic diseases including cardiovascular disorders, diabetes, and certain cancers (Baranski et al., 2014). The absence of pesticide and fertilizer residues further reduces the risk of toxic exposure, making naturally grown vegetables particularly beneficial for children, pregnant women, and other vulnerable groups. By enhancing both nutritional quality and food safety, natural farming supports long-term human health and well-being while addressing growing concerns about diet-related diseases.

Challenges to Adoption

Despite the significant ecological and nutritional benefits of natural farming in vegetable cultivation, its broad implementation is still limited by various factors. Yield volatility, especially in the initial transition from traditional chemical-based systems, has been recognized as a significant challenge, as decreased productivity directly threatens the financial stability of smallholder farmers (Khadse et al., 2018). Insufficient distribution of technical knowledge, along with reduced access to standardized bio-inputs like composts, bio-fertilizers, and botanical pesticides, hinders adoption. Additionally, inadequacies in institutional support systems, such as

certification procedures, supply chain logistics, and market entry, limit farmers' ability to obtain higher prices for naturally grown vegetables. Labor intensity is another significant drawback, as natural farming methods frequently demand considerable manual effort for enhancing soil, managing weeds, and controlling pests ecologically, thus elevating production expenses compared to traditional approaches. Deficiencies at the policy level, including the lack of specific subsidies and poor incorporation of natural farming into national agricultural systems, worsen these limitations. Together, these elements highlight the importance of systematic actions, such as research-driven innovations, capacity-building programs, and supportive policy tools, to enhance the scalability and sustainability of natural farming in vegetable production systems

Conclusion

Natural farming embodies a comprehensive and sustainable method for growing vegetables that combines ecological guidelines, soil revitalization, and nutritional improvement. Removing synthetic fertilizers and pesticides not only protects environmental health but also guarantees the cultivation of vegetables that have higher nutrient density, increased antioxidant levels, and minimal chemical residues. These qualities directly enhance food quality, prolong shelf life, and provide tangible advantages to human health, especially in lowering the risks linked to chronic illnesses and toxic exposures. Moreover, natural farming enhances soil fertility, fosters biodiversity, and lowers greenhouse gas emissions, thus aligning agricultural methods with wider sustainability objectives.

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Future Prospects of Artificial Intelligence in Vegetable Crop Production and Management



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Introduction

The production of vegetable crops is essential for global food and nutritional security. Vegetables provide abundant vitamins, minerals, and dietary fiber, but their production faces obstacles like rapid spoilage, pest and disease threats, labor requirements, and susceptibility to climate changes. Conventional agricultural methods frequently do not adequately tackle these issues, highlighting the need for advanced technologies to ensure sustainable and effective production. Artificial Intelligence (AI) has recently become a game-changing resource in agriculture, providing data-based solutions for crop surveillance, pest identification, irrigation control, and supply chain enhancement. Incorporating information from sensors, drones, and satellite images with machine learning techniques allows AI to facilitate real-time decision-making that enhances accuracy and effectiveness. In vegetable farming, where prompt actions are essential, AI aids in early identification of diseases, forecasting yields, and optimizing resources, thus lowering input expenses and post-harvest losses. AI is progressively influencing supply chains by predicting demand, streamlining logistics, and improving traceability. These solutions enhance farmers' profitability while also aiding sustainability objectives by reducing waste and saving resources.

Current Applications of AI in Vegetable Crop Management Crop Monitoring and Yield Prediction

Monitoring crops and predicting yields are key applications of Artificial Intelligence (AI) in vegetable farming. Conventional monitoring depends on manual field inspections, which are time-consuming and frequently limited in precision. AI combines remote sensing, drones, and ground-based sensors with machine learning and computer vision algorithms to deliver continuous, real-time information on crop health. Through examining changes in canopy cover, leaf hue, and soil moisture, AI systems can identify nutrient deficiencies, water stress, and early indications of pest or disease outbreaks long before observable symptoms worsen. This holds particular significance for vegetables, as they are perishable and need thorough planning for harvesting, storage, and sales. Accurate yield forecasts enable farmers and supply chain participants to enhance resource distribution, reduce post-harvest losses, and stabilize market values.



Pest and Disease Detection

In vegetable crop production, pests and diseases are significant limitations, frequently resulting in considerable yield reductions and diminished market quality. Traditional detection techniques depend on visual assessments or consultations with experts, making them tedious and susceptible to mistakes, especially in extensive or isolated agricultural systems. Artificial Intelligence (AI) provides more effective and precise solutions by employing computer vision, image recognition, and machine learning models to detect early signs of pest and disease presence. AI algorithms, educated on large image collections, can distinguish between healthy and unhealthy plant tissues, identifying problems like leaf spots, blight, mildew, or pest damage. Images taken with smartphones, drones, or field cameras can be assessed instantly, allowing farmers to implement prompt corrective actions.

Timely identification limits the transmission of infections and decreases the necessity for wide-range pesticide use, thus reducing expenses and lessening environmental effects.

Precision Irrigation and Water Management

Water management plays a vital role in vegetable crop production since many vegetables are particularly susceptible to water stress and need regular irrigation. Conventional irrigation techniques, typically reliant on rigid schedules, can cause either excessive or insufficient watering, leading to nutrient leaching, higher disease rates, decreased yields, and ineffective resource utilization. Artificial Intelligence (AI) has brought forth precision irrigation systems that enhance water usage by combining real-time information from soil moisture sensors, weather predictions, crop development models, and remote sensing technologies. In machine learning assess these datasets to identify the precise water needs of crops during various growth phases. Rather than using uniform irrigation throughout the field, AI facilitates targeted management, providing water exclusively where and when necessary.

Supply Chain Optimization

Vegetable crops are very susceptible to spoilage, and inefficiencies in storage, transportation, and distribution frequently lead to post-harvest losses of 30–40 percent. Optimizing supply chains with Artificial Intelligence (AI) offers efficient strategies to minimize losses, enhancing both profitability and sustainability. AI systems combine data from weather predictions, yield estimates, consumer demand patterns, and market prices to accurately forecast supply and demand dynamics. These findings facilitate improved harvest timing, effective storage organization, and prompt market distribution, minimizing waste and price variations. Cold-chain monitoring systems powered by AI improve quality maintenance by controlling temperature and humidity levels throughout storage and transportation.

Future Prospects of AI in Vegetable Crop Production

Predictive Analytics for Improved Yield

Predictive analytics, driven by Artificial Intelligence (AI), stands as one of the most promising upcoming applications in vegetable crop cultivation. Although existing AI models currently aid in yield estimation and monitoring, upcoming systems are anticipated to incorporate larger datasets and more sophisticated algorithms for providing precise and context-relevant predictions. These models will utilize various sources such as current weather data, soil health metrics, remote sensing images, market analysis, and past yield statistics, providing in-depth insights into crop performance. In vegetable farming, where quick decisions matter because of brief growth periods and high spoilage rates, predictive analytics can assist farmers in choosing the best sowing times, irrigation plans, and nutrient management techniques. Through the simulation of various scenarios, AI will aid in predicting possible risks like pest infestations, drought conditions, or severe weather occurrences, and recommend proactive strategies prior to affecting crop yields.

Automated Harvesting and Post-Harvest Management

Operations that require significant manual labor, such as harvesting and post-harvest management, continue to pose significant challenges in vegetable production, especially considering the fragile and perishable characteristics of crops like tomatoes, cucumbers, and leafy greens. Automated harvesting, enhanced by Artificial Intelligence (AI), is becoming a groundbreaking solution. Upcoming innovations in robotics combined with AI-based computer vision will allow machines to accurately assess the ripeness, size, and quality of vegetables, facilitating selective harvesting that reduces crop damage and guarantees consistent quality. Robots driven by AI are predicted to grow more affordable and versatile, rendering them practical not just for extensive greenhouse operations but also for vegetable cultivation in open fields. In addition to harvesting, AI applications in post-harvest management will improve grading, sorting, and packaging procedures.

Climate-Resilient Farming

Climate variability presents a major risk to vegetable production, since crops are very vulnerable to temperature extremes, erratic rainfall, drought, and pest infestations that worsen with shifting climates. Artificial Intelligence (AI) provides robust resources to enhance climate-resilient agriculture through predictive, adaptive, and sustainable management approaches. Upcoming AI systems will combine detailed climate data, soil metrics, and agricultural models to predict possible risks and assist farmers in adopting adaptive measures. AI-powered early alert systems can forecast severe weather incidents or health crises related to climate change, enabling farmers to

implement prompt preventive actions. Decision support platforms can suggest climate-smart strategies like adjusted planting times, improved irrigation planning, or selecting varieties suited for specific stress factors. Moreover, precision resource management powered by AI will aid in conserving limited inputs such as water and fertilizers, lowering susceptibility to drought and soil degradation.

Smart Greenhouse Management

Greenhouses are vital for vegetable production as they create managed conditions that improve yield, quality, and availability throughout the year. In greenhouse managing elements like temperature, humidity, ventilation, irrigation, and nutrient provision is very complicated and labor-demanding. Artificial Intelligence (AI) is becoming a revolutionary instrument for efficient greenhouse management through the facilitation of automation, accuracy, and immediate decision-making. Upcoming AI-driven systems will fully assemble with sensors, cameras, and climate control tools to consistently track environmental and crop conditions. In machine learning enhance the control of light levels, carbon dioxide amounts, and watering plans to ensure optimal growth environments. Computer vision will aid in monitoring plant development and identifying early signs of stress or disease, enabling prompt actions.

AI in Crop Breeding and Genetic Improvement

Crop breeding and genetic enhancements are crucial for creating vegetable varieties that are high-yielding, pest-resistant, resilient to climate changes, and nutritionally enhanced. Conventional breeding techniques, although successful, tend to be labor-intensive and require significant resources. Artificial Intelligence (AI) is poised to transform this field by speeding up the detection of favorable characteristics and enhancing breeding methods. AI and machine learning can examine large datasets from genomics, transcriptomics, phenotyping, and environmental factors to uncover associations with complex traits. Predictive models can connect genetic markers to favorable characteristics like disease resistance in tomatoes, drought resilience in cucumbers, or prolonged shelf life in leafy greens. This greatly shortens the breeding cycle duration in comparison to traditional methods. These insights enable breeders to make selections based on data with improved precision. Combining AI with genome-editing technologies like CRISPR significantly boosts the possibilities for precise genetic enhancements.

Challenges in Implementing AI in Vegetable Farming

High Cost of Technology

A significant challenge to implementing Artificial Intelligence (AI) in vegetable cultivation is the expensive nature of the technology. Sophisticated AI technologies like computer vision systems, self-operating robots, sensor networks, and machine learning platforms need considerable financial resources for hardware, software. For vegetable farmers of small and medium scale, who frequently work with constrained resources, such expenses are excessively high. This results in a gap where large agribusinesses can invest in AI technologies and small farmer cannot capable to invest in AI technologies.

Lack of Technical Knowledge

A significant challenge in implementing Artificial Intelligence (AI) in vegetable agriculture is the insufficient technical expertise among farmers. AI technologies, such as machine learning algorithms, drones, sensors, and automated irrigation systems, demand specific expertise for their operation, data analysis, and problem-solving. Numerous small and medium-sized farmers, especially in developing areas, possess restricted access to digital tools and modern agricultural technologies, limiting proper execution. Capacity-building initiatives are crucial for addressing this challenge. Training programs, workshops, and extension services can provide farmers with the knowledge and skills required to utilize AI-based systems effectively. User-friendly, simplified interfaces for AI applications, coupled with support for local languages, can improve accessibility even more.

Infrastructure Limitations

Infrastructure limitations represent a significant barrier to the adoption of Artificial Intelligence (AI) in vegetable farming. AI technologies rely on stable electricity, high-speed internet, cloud computing, and access to advanced sensors and devices. In many rural and remote agricultural regions, these facilities are either unreliable or completely unavailable, which restricts the effective deployment of AI-based solutions. Limited connectivity can hinder real-time data transmission from field sensors, drones, or automated machinery to cloud-based platforms, reducing the accuracy and timeliness of AI recommendations.

Recommendations for Promoting AI in Vegetable Farming Government Support

Government assistance is essential for the broad implementation of Artificial Intelligence (AI) in vegetable farming, especially for small and medium-sized farmers who encounter financial and technical challenges. Policy measures can offer financial support or low-interest loans for acquiring AI-driven technologies like sensors, drones, automated irrigation systems, and robotics. This financial assistance lowers the initial cost burden, allowing more farmers to access advanced technologies. Government-supported extension services and training programs can improve farmers' technical knowledge and digital literacy. This guarantees appropriate utilization of AI systems, enhances efficiency, and reduces mistakes. Regulatory structures for data privacy, cybersecurity, and ethical AI application in agriculture can enhance trust and facilitate secure adoption.

Farmer Training Programs

Training programs for farmers are crucial to guarantee the effective integration of Artificial Intelligence (AI) technologies in vegetable agriculture. Many farmers do not possess the technical skills needed to use AI-driven tools like sensors, drones, automated irrigation systems, and decision-support platforms. In the absence of adequate training, these technologies might be misused or not fully utilized, diminishing their effectiveness and restricting possible advantages.

Training programs ought to emphasize real-world, practical demonstrations of AI uses, such as monitoring crops, identifying pests and diseases, precision irrigation, and managing post-harvest activities. Farmers need to be trained in data analysis, system upkeep, and problem-solving to guarantee the effective and precise use of AI technologies. Holding workshops in native languages and tailoring content to local agricultural methods can improve comprehension and involvement.

Improved Infrastructure: Sufficient infrastructure is vital for the successful implementation of Artificial Intelligence (AI) in vegetable cultivation. AI technologies depend on reliable electricity, fast internet, cloud computing, and access to sophisticated sensors and automated equipment. In several rural and semi-urban regions, such facilities are either scarce or inconsistent, impeding farmers' capacity to fully utilize AI solutions. Creating regional digital hubs or agricultural technology centers can enable farmers to utilize AI tools without needing to individually possess expensive equipment. These facilities can additionally function as training and demonstration locations, illustrating real-world uses of AI in crop monitoring, precision irrigation, pest control, and post-harvest processing.

Conclusion

Artificial Intelligence (AI) has emerged as a transformative tool in vegetable crop production and management, offering solutions for crop monitoring, pest and disease detection, precision irrigation, automated harvesting, supply chain optimization, and climate-resilient farming. Current applications show significant improvements in productivity, resource efficiency, and post-harvest quality, while future prospects promise greater integration of predictive analytics, robotics, smart greenhouses, and AI-driven breeding for improved varieties.

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Nutrition Gardens – A Household Solution to Malnutrition



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Malnutrition continues to be one of the gravest public health challenges in India and across many developing countries. Despite significant improvements in agricultural production, the paradox of “hidden hunger” persists. Millions of households consume sufficient calories but remain deficient in essential micronutrients such as iron, zinc, vitamin A, and protein. This silent crisis manifests in widespread anemia, stunted growth among children, and poor maternal health outcomes. Against this backdrop, **nutrition gardens**—small, household-based or community-managed spaces for growing diverse fruits, vegetables, and pulses—are increasingly recognized as a sustainable and people-centric solution.



Why Nutrition Gardens Matter?



A nutrition garden is not merely a patch of greenery; it is an instrument of health security at the grassroots. By cultivating a variety of seasonal and locally adapted crops within the household premises or community spaces, families can ensure a continuous supply of fresh, pesticide-free, and nutrient-rich food. Unlike large-scale farming, which often focuses on monoculture cereals, nutrition gardens emphasize dietary diversity.

Studies have shown that households maintaining a nutrition garden are less vulnerable to food price fluctuations and market disruptions, while also enjoying

better dietary intake. For instance, homegrown spinach, drumstick leaves, and papaya are rich in iron and vitamin

A, directly combating anemia and night blindness. Similarly, legumes and pulses cultivated in small patches enhance protein consumption, vital for child growth and cognitive development.

Linking Nutrition to Empowerment

Nutrition gardens go beyond food they empower communities. Women, often the primary caretakers of household food and nutrition, play a central role in managing these gardens. By equipping women with training in composting, seed selection, and crop diversification, the approach strengthens their agency in family health decisions. Children too benefit by learning about local crops, biodiversity, and the importance of balanced diets, making the garden both a classroom and a kitchen.

A Sustainable Approach

Nutrition gardens fit seamlessly into the sustainable development agenda. They encourage the use of organic waste for compost, promote water-efficient practices such as drip irrigation, and safeguard agrobiodiversity by reviving forgotten local vegetables and millets. Importantly, they help households adapt to climate change by relying on hardy indigenous species that thrive in varied conditions.

Policy and Programmatic Momentum

The Government of India has recognized the potential of nutrition gardens under initiatives such as the **Poshan Abhiyaan**, the **ICDS Supplementary Nutrition Programme**, and **Krishi Vigyan Kendras (KVKs)**, which promote “nutri-sensitive agriculture.” Several states, including Odisha, Chhattisgarh, and Madhya Pradesh, have piloted large-scale household nutrition garden schemes. International organizations such as FAO and UNICEF also emphasize nutrition-sensitive food systems, with household gardens highlighted as a cornerstone strategy.

The Way Forward

To make nutrition gardens a household norm, certain steps are essential:

1. **Awareness Campaigns** – Popularize the benefits of nutrition gardens through schools, self-help groups, and rural health missions.
2. **Technical Support** – Provide households with seed kits, training in seasonal crop planning, and guidance on organic methods.
3. **Integration with Health Programs** – Link nutrition gardens with anganwadis and school mid-day meals to directly improve child nutrition.
4. **Community Models** – Encourage shared gardens in urban neighborhoods and rural panchayats where land is scarce.
5. **Monitoring Nutrition Outcomes** – Use village-level health indicators (anemia, stunting, BMI) to assess and refine garden-based interventions.

Conclusion

Nutrition gardens represent a **simple yet powerful household-level intervention** against malnutrition. They localize food production, diversify diets, and empower communities, especially women, to take charge of family health. In an era where lifestyle diseases and micronutrient deficiencies coexist with economic growth, such gardens are not just a means of survival but a pathway to resilience, dignity, and sustainable well-being. By turning backyards into sources of nourishment, nutrition gardens hold the promise of transforming the “Right to Food” into the “**Right to Nutrition.**”

Role of Biofertilizers in Green Leafy Vegetables: A Green Boost for Healthy Greens



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Abstract

Green leafy vegetables such as spinach, amaranth, fenugreek, and coriander are widely consumed for their exceptional nutritional value and health benefits. These crops, due to their short growth cycle and rapid biomass accumulation, require high and efficient nutrient input, particularly nitrogen and phosphorus. While chemical fertilizers have traditionally met these needs, their overuse has led to soil degradation, environmental pollution, and food safety concerns. In response, biofertilizers—microbial inoculants capable of enhancing nutrient availability through nitrogen fixation, phosphate solubilization, and plant growth stimulation—have emerged as sustainable alternatives. This article explores the significance of biofertilizers in leafy vegetable cultivation, highlighting their mechanisms, benefits, and application methods. Biofertilizers not only promote faster vegetative growth, higher yields, and improved crop quality but also contribute to soil health restoration and environmental sustainability. With the growing demand for residue-free and organically produced vegetables, integrating biofertilizers into leafy vegetable production systems offers a practical, eco-friendly, and economically viable solution for modern agriculture.

Keywords: Green leafy vegetables, Biofertilizers, Nitrogen fixation, Eco-friendly, Sustainable

Introduction

Green leafy vegetables such as spinach (*Spinacia oleracea*), amaranth (*Amaranthus spp.*), fenugreek (*Trigonella foenum-graecum*), and coriander (*Coriandrum sativum*) are among the most consumed vegetables in India and globally due to their rich nutritional profile. They are an excellent source of vitamins A, C, and K, iron, calcium, dietary fiber, and antioxidants that promote health and prevent chronic diseases (Nayak *et al.*, 2015). These crops are characterized by their short life cycle and rapid biomass accumulation, which necessitates a consistent and readily available nutrient supply, particularly nitrogen and phosphorus.

Traditionally, synthetic fertilizers have been applied to meet these nutritional requirements. However, the excessive and imbalanced use of chemical fertilizers has resulted in soil degradation, nutrient imbalance, contamination of water resources, and accumulation of harmful residues in vegetables (Tilman *et al.*, 2002; Bhardwaj *et al.*, 2014). This has raised serious concerns about food safety, environmental sustainability, and the long-term viability of conventional farming systems.

In this context, biofertilizers—which are formulations of beneficial microorganisms—have gained significant importance as eco-friendly inputs. These microbial inoculants enhance nutrient availability through biological nitrogen fixation, phosphorus solubilization, and synthesis of growth-promoting substances (Vessey, 2003). Their application improves soil fertility, boosts plant growth, and increases yield without the negative impacts associated with chemical fertilizers (Kumar *et al.*, 2017). Particularly in leafy vegetable cultivation, where rapid vegetative growth is critical, biofertilizers can significantly enhance quality, safety, and sustainability of produce.

As the demand for residue-free, organically grown vegetables continue to rise, integrating biofertilizers into the cultivation of green leafy vegetables emerges as a promising strategy. It not only ensures improved plant performance but also contributes to long-term soil health and environmental conservation (Sahu *et al.*, 2021).

What are Biofertilizers?

Biofertilizers are natural fertilizers that contain living microorganisms—such as bacteria, fungi, or cyanobacteria—which, when applied to seeds, plant surfaces, or soil, colonize the rhizosphere or plant interior and promote growth by increasing the availability or uptake of primary nutrients (Vessey, 2003).

They work through various mechanisms such as:

- Nitrogen fixation (e.g., *Azotobacter*, *Azospirillum*, *Rhizobium*)

- Phosphate solubilization (e.g., *Bacillus*, *Pseudomonas*)
- Potassium mobilization, and
- Symbiotic associations like mycorrhizae that enhance water and nutrient absorption.

Biofertilizers are eco-friendly, cost-effective, and help improve soil fertility and plant productivity without the adverse effects associated with chemical fertilizers (Subba Rao, 2013).

Why Biofertilizers are useful for Green leafy vegetables?

Leafy vegetables have a short growth cycle and a high nutrient demand, particularly for nitrogen and phosphorus. Biofertilizers help in making these nutrients readily available in a sustainable way. For example:

- *Azospirillum* and *Azotobacter* fix atmospheric nitrogen, converting it into a form usable by plants, thereby enhancing leafy growth (Subba Rao, 2013).
- Phosphate-solubilizing bacteria convert insoluble phosphorus in soil into soluble forms, improving root development and nutrient use efficiency (Rodríguez and Fraga, 1999).
- Mycorrhizal fungi improve water and micronutrient absorption and enhance plant resistance to pathogens and environmental stress.

Using biofertilizers in leafy vegetable cultivation promotes better plant establishment, quicker growth, and higher quality harvests while preserving soil health and minimizing environmental impact.

Benefits of Biofertilizers in Green leafy vegetables

1. **Faster Growth:** Nitrogen-fixing bacteria provide a continuous supply of nitrogen, stimulating lush vegetative growth in leafy crops (Kumar *et al.*, 2017). This leads to early harvesting and higher turnover for farmers.
2. **Higher Yield:** Studies have shown that combining biofertilizers with organic inputs can increase the yield of green leafy vegetables by 15–30% over control treatments (Mahato *et al.*, 2020).
3. **Improved Quality:** Biofertilizer-treated crops exhibit enhanced chlorophyll content, leaf area, and moisture retention, leading to tender and greener leaves with higher nutritional value (Chandrasekaran *et al.*, 2019).
4. **Soil Health:** Continuous use of chemical fertilizers depletes soil microbes, while biofertilizers restore and maintain beneficial microbial populations, improving soil structure and fertility (Sinha *et al.*, 2016).
5. **Eco-friendly and Sustainable:** Biofertilizers reduce the reliance on synthetic fertilizers, cutting down greenhouse gas emissions and preventing nitrate leaching and water pollution (Sahu *et al.*, 2021).

How to Use Them?

Biofertilizers can be applied in several ways depending on the crop and growing conditions:

- **Seed Treatment:** Seeds are soaked in a slurry of biofertilizer before sowing to ensure early microbial colonization.
- **Soil Application:** Biofertilizers are mixed with compost or farmyard manure and applied to the soil at the time of land preparation.
- **Foliar Spray:** Liquid biofertilizers can be sprayed on leaves for quick absorption.

Maintaining adequate soil moisture, avoiding chemical pesticide overdose, and using well-decomposed organic matter can significantly enhance the performance of biofertilizers (Reddy and Saravanan, 2013).

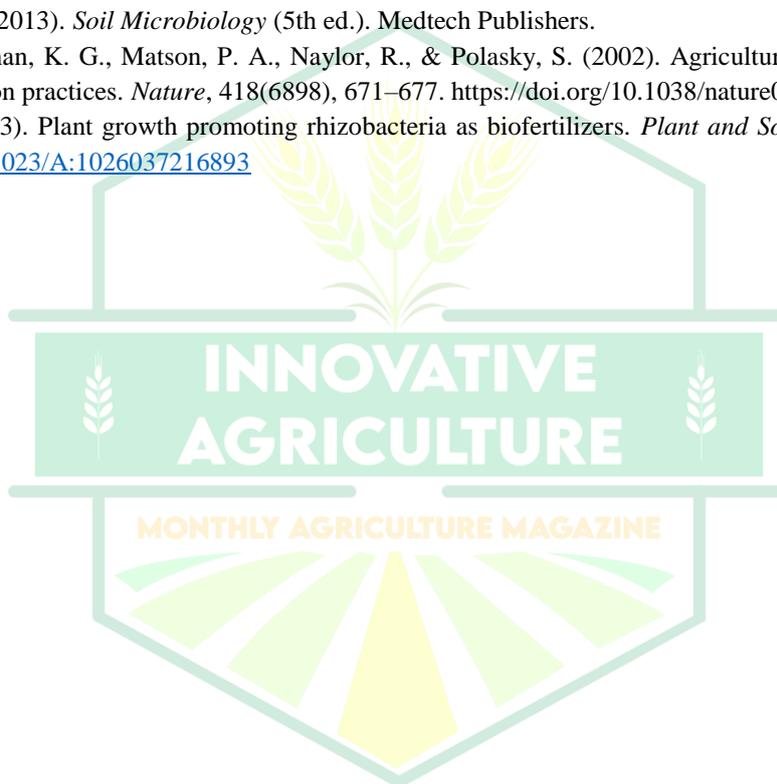
Conclusion

Biofertilizers offer a reliable, sustainable, and eco-friendly approach to cultivating green leafy vegetables. Their role in enhancing nutrient availability, improving yield and quality, and preserving soil health makes them a vital tool in organic and integrated farming systems. As consumers increasingly demand safe and residue-free vegetables, adopting biofertilizers in leafy vegetable production is not only beneficial for the environment but also for public health and economic sustainability.

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A Global Review on Postharvest Losses in Vegetables: Causes, Impacts, and Mitigation Strategies



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Abstract

Postharvest losses (PHL) of vegetables constitute a critical global challenge with profound economic, nutritional, and environmental implications. Globally, 30–50% of vegetables are lost after harvest due to a combination of biological, technological, and socioeconomic factors. These losses are highest in developing countries due to inadequate storage facilities, inefficient transportation, and poor postharvest management practices, whereas developed nations also face losses primarily due to consumer preferences and supply chain inefficiencies. This paper presents a comprehensive review of the magnitude, causes, impacts, and mitigation strategies for postharvest losses in vegetables. It explores preharvest, harvesting, handling, storage, packaging, transportation, and policy-related factors, emphasizing the integration of technological, institutional, and community-based solutions. Mitigation strategies, including cold chain management, improved harvesting techniques, advanced packaging, awareness programs, and policy interventions, are discussed in detail. Emerging technologies such as smart sensors, AI-enabled logistics, and biodegradable packaging are highlighted as potential solutions for sustainable reduction of postharvest losses. The paper concludes with future research directions, focusing on the development of integrated systems to minimize losses and enhance food security, economic efficiency, and environmental sustainability globally.

Keywords: Postharvest losses, Vegetables, Cold chain management, Packaging technologies, Supply chain efficiency, Food security, Sustainability, Mitigation strategies

1. Introduction

Vegetables are fundamental components of a healthy diet, providing essential micronutrients, vitamins, and dietary fiber. They contribute significantly to global food security and nutritional well-being. Despite advances in agriculture, a substantial proportion of vegetables are lost after harvest, limiting their availability and increasing production costs. Postharvest losses (PHL) refer to any measurable reduction in quantity or quality of vegetables along the postharvest supply chain, from harvest to consumption.

Globally, it is estimated that **30–50% of vegetable production is lost postharvest**, with higher percentages in perishable crops such as leafy greens, cucumbers, and tomatoes. These losses are not only economic but also affect nutrition, food availability, and the environment due to wasted water, energy, and land resources. In developing countries, infrastructural gaps, lack of cold storage, and poor transportation are major contributors, whereas in developed countries, consumer preferences for aesthetically perfect vegetables and prolonged storage also lead to losses.

The objective of this paper is to provide a comprehensive global review of postharvest losses in vegetables, including:

1. The magnitude and global trends of PHL.
2. Causes at preharvest, harvest, handling, storage, and transportation stages.
3. Economic, nutritional, and environmental impacts.

4. Mitigation strategies involving technology, policy, and education.
5. Future directions to achieve sustainable postharvest management.

2. Magnitude of Postharvest Losses in Vegetables

2.1. Global Statistics

Vegetables are highly perishable, and global PHL is estimated to range between 30–50% depending on the crop, region, and season. Some key observations include:

- Leafy vegetables (lettuce, spinach, coriander) suffer losses of up to 55% due to their high moisture content and fragile tissues.
- Fruits such as tomatoes and cucumbers have losses ranging from 30–40%.
- Root and tuber vegetables (carrot, beetroot) experience slightly lower losses, often 20–30%, due to tougher skins.

2.2. Regional Variations

- **Asia:** Developing countries like India, Bangladesh, and Nepal experience high losses (40–50%) due to inadequate storage, poor transportation, and market inefficiencies.
- **Africa:** Sub-Saharan Africa faces 30–45% losses; lack of cold chains and market access are key constraints.
- **Europe & North America:** Losses are lower (15–25%), mainly due to technological advancements, cold chain systems, and improved handling practices, though consumer-driven cosmetic rejection also contributes.

2.3. Crop-Specific Analysis

Vegetable Type	Average PHL (%)	Major Causes
Leafy greens	45–55	Wilting, microbial spoilage
Tomatoes	30–40	Mechanical damage, ripening losses
Cucumbers	30–35	Moisture loss, handling damage
Carrots	20–25	Storage fungi, improper humidity
Bell peppers	25–35	Physical damage, decay

3. Causes of Postharvest Losses

3.1 Preharvest Factors

1. **Crop Management:** Inadequate irrigation, pest infestations, and suboptimal fertilization reduce plant vigor and shelf life.
2. **Pests and Diseases:** Plants stressed by pathogens (e.g., Fusarium in tomatoes) produce less durable fruits prone to decay.
3. **Environmental Stress:** Temperature extremes, drought, or excessive rainfall impact the quality and storability of harvested vegetables.

3.2 Harvesting Practices

1. **Timing:** Harvesting vegetables either too early or too late affects nutritional content and susceptibility to spoilage.
2. **Handling:** Rough handling, dropping, or overpacking causes bruising and accelerates microbial decay.
3. **Manual vs Mechanical Harvesting:** Manual harvesting preserves quality but is labor-intensive; mechanical harvesting can increase damage if not carefully calibrated.

3.3 Postharvest Handling and Storage

1. **Temperature and Humidity Management:** Vegetables require specific storage conditions; for example, leafy greens need 0–5°C and 95–98% relative humidity. Failure to maintain these conditions accelerates senescence and microbial growth.
2. **Sanitation:** Contaminated storage areas can increase microbial load, leading to faster spoilage.
3. **Sorting and Grading:** Lack of proper sorting may lead to mixing of high- and low-quality produce, increasing overall losses.

3.4 Packaging and Transportation

1. **Packaging:** Use of inappropriate containers leads to crushing, bruising, or exposure to contaminants. Modified atmosphere packaging (MAP) can reduce respiration and extend shelf life.
2. **Transportation:** Delays, vibration, and exposure to sunlight or rain can increase physical and physiological damage.
3. **Cold Chain Breakdowns:** Interruptions in the cold chain exacerbate spoilage, particularly for high-moisture vegetables.

3.5 Socioeconomic and Infrastructure Constraints

1. **Infrastructure Deficiencies:** Lack of warehouses, refrigerated trucks, and market facilities is common in developing countries.
2. **Economic Constraints:** Farmers often lack capital to invest in storage and transport improvements.
3. **Knowledge Gaps:** Insufficient awareness of proper postharvest practices among farmers and traders leads to avoidable losses.

4. Impacts of Postharvest Losses

4.1 Economic Impacts

1. Farmers lose potential income due to spoiled produce.
2. Traders face reduced profitability due to weight loss, quality degradation, and rejection by buyers.
3. National economies suffer from reduced agricultural efficiency and higher food import needs.

4.2 Nutritional and Food Security Impacts

1. Loss of vegetables reduces access to essential vitamins (A, C, folate) and minerals (iron, calcium).
2. Vulnerable populations, especially in low-income countries, are disproportionately affected.
3. Postharvest losses exacerbate malnutrition and food insecurity.

4.3 Environmental Impacts

1. Wasted vegetables represent lost water, energy, and land resources.
2. Decomposing waste contributes to greenhouse gas emissions (methane).
3. Reduced production efficiency increases pressure to expand agricultural land, leading to deforestation and biodiversity loss.

5. Mitigation Strategies

5.1 Improved Harvesting Techniques

1. Proper timing of harvest to balance maturity and storability.
2. Use of soft tools and trays to prevent bruising.
3. Training programs for farmers on best harvesting practices.

5.2 Efficient Storage and Cold Chain Management

1. Cold rooms and refrigerated transport to slow respiration and microbial growth.
2. Controlled Atmosphere (CA) storage to reduce oxygen and increase CO₂ for shelf-life extension.
3. Solar-powered cold storage solutions for regions lacking electricity.

5.3 Packaging Innovations

1. Use of MAP and vacuum packaging to slow senescence.
2. Biodegradable and recyclable materials to reduce environmental impact.
3. Cushioning materials to prevent mechanical damage.

5.4 Transportation and Logistics Optimization

1. Improved roads and refrigerated transport reduce transit time and losses.
2. Logistics planning to ensure timely distribution from farm to market.
3. Load management and stacking protocols to prevent crushing.

5.5 Policy and Institutional Interventions

1. Subsidies and incentives for cold storage and transport infrastructure.
2. Regulatory standards for postharvest handling and hygiene.
3. Support for farmer cooperatives to pool resources and reduce individual costs.

5.6 Awareness and Capacity Building

1. Extension services to educate farmers and traders on best practices.

2. Workshops on nutrition and food security to highlight the importance of reducing PHL.
3. Public campaigns to reduce consumer-driven cosmetic rejections.

5.7 Emerging Technologies

1. **Smart Sensors:** Monitor temperature, humidity, and gas composition in storage units.
2. **AI and IoT Solutions:** Predict spoilage, optimize transport routes, and manage inventory.
3. **Nano-packaging:** Antimicrobial films to reduce microbial growth.

6. Future Directions and Research Needs

1. Integration of postharvest management with precision agriculture.
2. Research on crop varieties with improved shelf life.
3. Development of cost-effective cold chain technologies for smallholder farmers.
4. Modeling and data analytics to predict and reduce losses across supply chains.
5. Policy research to incentivize sustainable postharvest management practices.

7. Conclusion

Postharvest losses of vegetables represent a significant threat to global food security, economic stability, and environmental sustainability. Losses arise from preharvest, harvest, handling, storage, packaging, and transportation inefficiencies. The consequences are economic, nutritional, and environmental. Effective mitigation requires a multi-pronged approach, including improved harvesting, cold chain management, packaging innovations, optimized logistics, policy support, and capacity building. Emerging technologies, such as AI-driven logistics, smart sensors, and biodegradable packaging, offer promising solutions for reducing postharvest losses. Coordinated global efforts are essential to minimize losses, enhance food availability, and promote sustainable agriculture.

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Influence of Climate Change on Pest Populations and Natural Enemy Relationships in Agricultural Systems



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Abstract

Climate change has emerged as one of the most significant challenges to sustainable agriculture globally. Altered climatic conditions—including rising temperatures, changing rainfall patterns, increased atmospheric carbon dioxide (CO₂) levels, and extreme weather events—are significantly influencing pest populations and the dynamics of their natural enemies. These changes have profound implications for crop health, productivity, and food security. Pests may exhibit increased reproduction rates, faster development, expanded geographical ranges, and enhanced survival under altered climatic conditions. Conversely, natural enemies such as predators, parasitoids, and pathogens may experience disrupted life cycles, altered abundance, and reduced effectiveness in regulating pest populations. This paper provides a comprehensive review of the influence of climate change on pest populations and natural enemy interactions, examining current research, mechanisms, case studies, and implications for integrated pest management (IPM) strategies. Strategies for adaptation, mitigation, and future research directions are discussed to support sustainable agriculture under changing environmental conditions.

Keyword: Climate change, Pest populations, Natural enemies, Integrated pest management (IPM), Sustainable agriculture, Food security, Adaptation strategies

1. Introduction

Agricultural ecosystems are dynamic systems in which plants, pests, and natural enemies interact within environmental constraints. Climate change introduces unprecedented variability to these systems, affecting crop growth, pest behavior, and the effectiveness of natural enemies. Pests, including insects, mites, nematodes, and pathogens, pose a constant threat to crop production, causing yield losses ranging from 10% to over 30% in severe cases. Natural enemies—predators, parasitoids, and entomopathogens—play a critical role in suppressing pest populations, thus maintaining ecological balance and supporting sustainable agriculture.

The effects of climate change on pest and natural enemy dynamics are multifaceted. Rising temperatures, altered precipitation patterns, increased frequency of extreme weather events, and elevated CO₂ concentrations can impact physiological, behavioral, and ecological traits of both pests and their natural enemies. Understanding these interactions is essential to develop climate-resilient pest management strategies and maintain global food security. This paper examines the current state of knowledge regarding the influence of climate change on pest populations and their natural enemies, emphasizing the mechanisms of change, examples from major crops, and implications for integrated pest management.

2. Climate Change Factors Affecting Agroecosystems

2.1. Rising Temperatures

Global surface temperatures have increased by approximately 1.1°C since pre-industrial times, and projections indicate further warming of 1.5–4°C by the end of the 21st century. Temperature is a critical determinant of insect

physiology, metabolism, reproduction, and survival. Higher temperatures can accelerate insect development, reduce generation times, and increase voltinism (number of generations per year). For example:

1. Aphids reproduce faster at higher temperatures, enabling multiple generations within a single growing season.
2. Lepidopteran pests, such as armyworms and bollworms, exhibit shorter life cycles under warmer conditions, resulting in more frequent outbreaks.

Temperature also affects the survival and distribution of pests in previously unsuitable regions. In temperate regions, warming allows tropical and subtropical pests to expand their range, threatening new crop systems.

2.2. Altered Precipitation Patterns

Changes in precipitation patterns—ranging from prolonged droughts to intense rainfall events—affect both pest populations and natural enemies. Drought conditions often stress crops, reducing their resistance to herbivores and increasing susceptibility to pest attacks. Conversely, excessive rainfall can physically disrupt pest life cycles, wash away eggs, or reduce the survival of immature stages.

For instance:

1. Drought-stressed maize is more susceptible to fall armyworm infestations.
2. Excessive rainfall can hinder predator activity, such as lady beetles and lacewings, reducing natural pest control.

2.3. Elevated CO₂ Concentrations

Atmospheric CO₂ levels have risen from ~280 ppm in pre-industrial times to over 420 ppm today. Elevated CO₂ affects plant physiology by altering photosynthesis, carbon-to-nitrogen ratios, and secondary metabolites. These changes influence herbivorous pests by:

1. Increasing leaf biomass but reducing nitrogen content, leading pests to consume more foliage to meet nutritional requirements.
2. Modifying plant secondary metabolites, which can alter pest growth, survival, and fecundity.

Some studies indicate that elevated CO₂ can enhance pest reproduction rates despite lower leaf nitrogen, as insects compensate for reduced nutritional quality by consuming more plant tissue.

2.4. Extreme Weather Events

Climate change has increased the frequency of extreme events such as heatwaves, storms, floods, and unseasonal frosts. These events can:

1. Disrupt pest populations through habitat destruction or mortality.
2. Affect natural enemy populations, causing temporary mismatches in predator-prey interactions.
3. Facilitate pest invasions into stressed crop systems.

3. Impacts of Climate Change on Pest Populations

3.1. Changes in Pest Distribution and Range Expansion

As temperatures rise, many pests are shifting poleward or to higher altitudes. For example:

1. The fall armyworm (*Spodoptera frugiperda*), originally native to the Americas, has invaded Africa and Asia, facilitated by warmer conditions and human-mediated transport.
2. The diamondback moth (*Plutella xylostella*), a major crucifer pest, now exhibits year-round activity in regions where it was previously seasonal.

Range expansions pose challenges for pest monitoring and control, as previously unaffected regions may lack natural enemy populations or IPM infrastructure.

3.2. Altered Life Cycles and Reproduction

Temperature and precipitation influence pest life cycles. Warmer conditions shorten developmental periods, increase reproductive rates, and enhance survival of immature stages. This can lead to:

1. Increased voltinism and higher pest population densities.
2. Greater risk of simultaneous infestations by multiple pest species.
3. Higher potential for pesticide resistance due to rapid generational turnover.

3.3. Emergence of New Pest Species

Climate change facilitates the emergence of invasive species in regions where they were previously absent. Invasive pests can disrupt local agroecosystems, outcompete native pests, and reduce the effectiveness of natural enemies. Examples include:

1. Red palm weevil in the Middle East.
2. Tomato leaf miner (*Tuta absoluta*) in Africa and Asia.

4. Effects on Natural Enemies

4.1. Predators

Natural predators are sensitive to temperature, humidity, and prey availability. Elevated temperatures can:

1. Increase predator metabolism, requiring higher prey consumption.
2. Shift activity periods, creating temporal mismatches with pest peaks.
3. Reduce overwintering survival of certain predatory insects.

Lady beetles, spiders, and predatory bugs may become less effective if pests develop faster than predators can respond.

4.2. Parasitoids

Parasitoids are highly host-dependent. Climate change can:

1. Alter host availability, affecting parasitoid reproduction and survival.
2. Reduce parasitoid efficiency if host development accelerates beyond parasitoid capacity.
3. Lead to phenological mismatches, with pests reproducing before parasitoids are active.

4.3. Pathogens

Entomopathogenic fungi, bacteria, and viruses are natural pest suppressors. Temperature, humidity, and rainfall patterns influence their survival and virulence. For example:

1. High temperatures may reduce fungal spore viability.
2. Heavy rainfall can wash away microbial pathogens from crops.

5. Disruption of Pest-Natural Enemy Interactions

5.1. Phenological Mismatches

Climate-induced changes in the timing of life cycle events can lead to asynchrony between pests and natural enemies. When pests emerge before or after the activity of predators or parasitoids, natural pest control is compromised.

5.2. Altered Host Quality

Stress conditions in crops—such as drought or nutrient limitation—affect the nutritional value of pests for their natural enemies. Poor-quality hosts may reduce parasitoid survival or predator efficiency.

5.3. Food Web Disruptions

Climate change can alter community composition, affecting multi-trophic interactions:

1. Some natural enemies may decline, leading to pest outbreaks.
2. Altered predator-prey ratios can destabilize ecosystem services.
3. Invasive pests may escape regulation due to absence of local natural enemies.

6. Implications for Integrated Pest Management (IPM)

Adaptation of IPM strategies is essential to address climate-induced changes:

6.1. Monitoring and Early Warning Systems

1. Predictive models incorporating climatic variables can forecast pest outbreaks.
2. Remote sensing and GIS-based tools support timely interventions.
3. Early-warning systems help optimize pesticide application and reduce unnecessary use.

6.2. Biological Control Enhancement

1. Habitat manipulation (flower strips, refuges) supports natural enemies.
2. Conservation biological control maintains predator and parasitoid populations.
3. Introduction of climate-resilient natural enemies can improve control efficiency.

6.3. Cultural and Mechanical Methods

1. Crop rotation, intercropping, and mulching reduce pest colonization.
2. Physical barriers and traps help control pests without chemical inputs.

6.4. Chemical Control Adaptation

1. Pesticides should be used judiciously to avoid resistance development.
2. Climate-driven changes in pest phenology may require revised spray schedules.

7. Case Studies

7.1. Fall Armyworm (*Spodoptera frugiperda*)

1. Native to the Americas, it invaded Africa in 2016 and Asia in 2018.
2. Climate change facilitated its establishment in tropical and subtropical regions.
3. Integrated management includes monitoring, biocontrol agents (parasitoids, fungi), and resistant varieties.

7.2. Aphids in Europe

1. Early warming accelerates aphid reproduction, leading to earlier infestations.
2. Natural enemies (lady beetles, parasitic wasps) may emerge later, reducing control efficiency.
3. IPM strategies require real-time monitoring and targeted interventions.

7.3. Desert Locusts

1. Erratic rainfall and temperature shifts have triggered unprecedented locust swarms in Africa, the Middle East, and South Asia.
2. Swarm outbreaks devastate cereal and forage crops, threatening food security.
3. Biological control (fungal pathogens) and predictive monitoring are critical management tools.

8. Future Research Directions

1. **Predictive Modeling:** Incorporating climate variables into pest and natural enemy population models.
2. **Genomic Studies:** Understanding genetic adaptation of pests and natural enemies to climate stressors.
3. **Agroecological Practices:** Developing sustainable, biodiversity-friendly farming systems.
4. **Climate-Resilient Biocontrol:** Identifying and deploying natural enemies capable of surviving extreme conditions.
5. **Food Security Integration:** Linking pest management with crop yield projections under climate change.

9. Conclusion

Climate change poses a complex challenge for agricultural pest management. By altering pest populations, disrupting natural enemy interactions, and modifying ecological balance, climate change threatens crop productivity and global food security. Sustainable and adaptive strategies—including enhanced monitoring, biological control, cultural practices, and climate-resilient IPM—are essential to mitigate these impacts. Collaborative research, predictive modeling, and policy support will be crucial for ensuring resilient agroecosystems in a changing climate.

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CRISPR and Genome Editing in Crop Improvement: Advancing Food Security and Resilience



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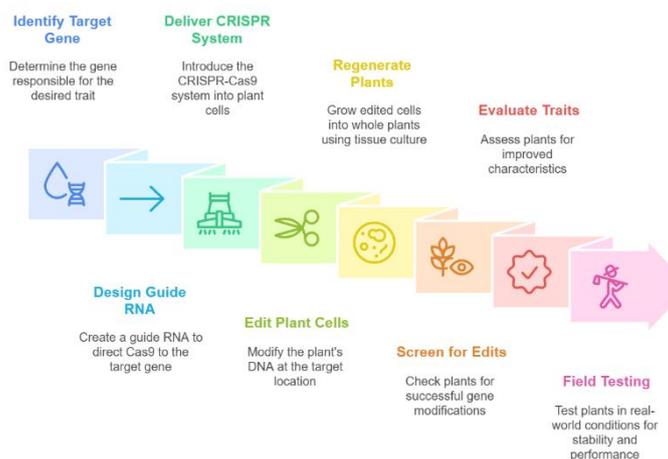
Introduction

Projecting a near 60% increase in global food demand by the year 2050 due to burgeoning population growth, shifts in dietary patterns, and urbanization presents significant challenges to contemporary agriculture. Traditional crop breeding methodologies have played a critical role in historical agricultural advancements; however, these approaches are frequently hindered by protracted breeding cycles, genetic bottlenecks, and diminished adaptability to the increasing frequency of biotic and abiotic stresses. In this milieu, the emergence of modern biotechnological tools, particularly those utilizing CRISPR-Cas (Clustered Regularly Interspaced Short Palindromic Repeats) genome editing, signifies a paradigm shift in crop improvement strategies.

CRISPR technology facilitates precise, efficient, and relatively cost-effective modifications of plant genomes. In contrast to conventional genetic modification techniques, which predominantly rely on transgenic methods involving the incorporation of foreign genetic material, CRISPR permits targeted gene editing encompassing gene knockouts, insertions, and base editing without the necessity of integrating exogenous DNA. This fundamental distinction carries substantial implications regarding public perception and regulatory frameworks associated with genetically modified organisms (GMOs).

The applications of CRISPR technology within agricultural contexts are rapidly expanding, encompassing enhancements in yield potential, disease resistance, and stress tolerance, as well as improvements in nutritional quality and shelf life of crops. Documented successes in the application of genome editing are evident in staple crops such as rice, wheat, maize, soybean, as well as various horticultural species. These advancements illuminate the pivotal role of CRISPR and genome editing as foundational elements of next-generation plant breeding and underscore their potential to significantly contribute to food security and resilience in the face of a changing global agricultural landscape.

CRISPR Technology for Crop Improvement



Applications of CRISPR in Crop Improvement

The versatility of CRISPR-Cas systems has increasingly empowered researchers to address a range of constraints impacting crop production and quality. The following sections elaborate on key areas of application where CRISPR technology is making significant contributions.

1. Yield Enhancement

CRISPR technology has been utilized to edit genes that govern various aspects of plant architecture and flowering time, leading to enhanced yield potential. For instance, the editing of the *Gn1a* and *DEP1* genes in rice has resulted in notable improvements in grain number and panicle size. Similarly, genome editing in maize has effectively

optimized kernel row number, an essential determinant of overall productivity. These genetic modifications present opportunities to augment crop yields in a more targeted and efficient manner.

2. Biotic Stress Resistance

The vulnerability of crops to pathogens and pests is a major contributor to yield losses on a global scale. CRISPR-mediated knockouts of MLO (Mildew Resistance Locus O) genes in wheat have demonstrated effectiveness in conferring resistance to powdery mildew, while targeted editing of susceptibility genes in tomato has enhanced resistance against bacterial speck disease. These precision interventions not only mitigate reliance on chemical pesticides but also contribute to sustainable agricultural practices by promoting healthier ecosystems.

3. Abiotic Stress Tolerance

The challenges posed by abiotic stresses such as drought, salinity, and heat are becoming increasingly pertinent in the context of climate change. In rice, CRISPR has been employed to modify OsPYL (abscisic acid receptor) genes, leading to enhanced drought tolerance. Additionally, genome editing of salt-sensitive genes in soybean and tomato has been shown to improve plant growth and resilience under saline conditions. Such genetic advancements provide critical tools to develop crops that can withstand variable environmental stresses.

4. Nutritional Quality and Biofortification

A pivotal focus of biofortification programs is the enhancement of the nutritional value of staple crops. CRISPR technology has been effectively applied to increase provitamin A content in rice and to elevate levels of γ -aminobutyric acid (GABA) in tomato. These enhancements contribute to significant improvements in nutritional outcomes for consumers. Furthermore, in oilseed crops, editing of fatty acid biosynthesis genes has led to a better balance of health-promoting lipids, demonstrating the potential of CRISPR in addressing nutritional deficiencies.

5. Post-Harvest Traits and Shelf Life

Gene editing offers promising solutions to post-harvest losses, which account for a considerable proportion of global food waste. In tomatoes, CRISPR-mediated modifications of RIN (Ripening Inhibitor) genes have effectively extended fruit shelf life without compromising flavour or nutritional content. Such innovations carry substantial implications for the stability of food supply chains and market sustainability, ultimately contributing to enhanced food security.

6. De Novo Domestication of Wild Relatives

An innovative application of CRISPR technology involves the acceleration of the domestication process for wild species possessing desirable traits, particularly those related to stress tolerance. For example, wild relatives of tomatoes have been rapidly improved for fruit size and yield through targeted genome editing, successfully bypassing the extensive timelines typically required in conventional breeding programs. This approach not only accelerates the introduction of beneficial traits but also broadens the genetic diversity available for crop enhancement.

Case Studies of CRISPR-Edited Crops

As CRISPR technology continues to evolve, its application in agricultural biotechnology is becoming increasingly prominent. This section presents notable case studies that exemplify the successful implementation of CRISPR editing in various crops, showcasing advancements aimed at improving disease resistance, yield, nutritional quality, and overall sustainability in agriculture.

1. Rice

Rice serves as one of the most extensively researched crops concerning CRISPR applications. In a landmark study conducted in China, the editing of the OsSWEET gene family resulted in durable resistance to bacterial blight, a pathogen that significantly diminishes rice yields across Asia. Concurrently, modifications to the Gn1a and DEP1 genes have been associated with increased grain number and enhanced panicle architecture. These genetic advancements directly contribute to food security in regions heavily reliant on rice production, thereby addressing critical agricultural challenges.

2. Wheat

Powdery mildew poses a severe threat to wheat crops, and recent research at the Chinese Academy of Sciences has highlighted the efficacy of CRISPR in combating this issue. By successfully editing the TaMLO gene, researchers have produced wheat lines that exhibit resistance to powdery mildew while maintaining yield levels.

This breakthrough not only signifies progress in reducing reliance on chemical fungicides but also enhances the sustainability of wheat cultivation practices.

3. Maize

In the United States, CRISPR technology has been employed to modify genes that govern kernel development and drought resilience in maize. Corteva Agriscience has developed specific maize lines that exhibit improved yield stability under water-limited conditions, showcasing CRISPR's potential in enhancing climate resilience. This innovative application reflects the growing need for crops that can withstand the increasingly unpredictable environmental conditions associated with climate change.

4. Tomato

Advancements in tomato improvement through CRISPR technology are progressing rapidly. Researchers in Japan have successfully developed tomatoes containing elevated levels of γ -aminobutyric acid (GABA), a bioactive compound linked to the regulation of blood pressure. Notably, this CRISPR-edited tomato was the first genome-edited crop to be commercially released in Japan in 2021, marking a significant milestone in regulatory acceptance and the integration of genetically edited crops into consumer markets.

5. Soybean

In both the United States and Argentina, researchers have leveraged CRISPR to develop soybeans with enhanced oil profiles. These CRISPR-edited varieties exhibit increased concentrations of oleic acid while simultaneously reducing levels of linolenic acid. Such modifications not only improve oil stability and nutritional quality but also open up new avenues for industrial applications, thereby adding economic value for farmers and consumers alike.

6. Banana

Globally, banana production is under threat from Panama disease, specifically strains such as Fusarium wilt TR4. Research endeavours in Australia and Africa are utilizing CRISPR technology to engineer resistant banana varieties through the targeted editing of susceptibility genes. Should these efforts prove successful, they have the potential to protect this vital tropical fruit from devastating losses, significantly impacting food security and the livelihoods of those dependent on banana cultivation.

Challenges and Limitations of CRISPR in Agriculture

Despite the considerable promise that CRISPR technology holds for crop improvement, several challenges obstruct its widespread application. These challenges can be categorized into technical, regulatory, ethical, and socio-economic dimensions.

1. Technical Constraints

While CRISPR offers a remarkable level of precision in gene editing, the potential for unintended edits, known as off-target mutations, remains a significant concern. Ensuring editing accuracy is particularly crucial in polyploid crops, such as wheat, where multiple copies of genes complicate the targeting process. Moreover, the efficient delivery of CRISPR components into plant cells, which typically necessitates transformation or the use of gene-editing tools, continues to pose a bottleneck for many crop species.

2. Regulatory Ambiguity

The regulatory landscape for genome-edited crops is highly heterogeneous across different jurisdictions. For example, the United States adopts a relatively permissive stance on crops edited by CRISPR, particularly when no foreign DNA is introduced. Conversely, the European Union applies stringent regulations to genome-edited crops, categorizing them alongside transgenic organisms. This disparity in regulatory frameworks impedes global trade and complicates the adoption of genome-edited crops on an international scale.

3. Ethical and Public Perception Issues

Public acceptance of genome-edited crops is significantly influenced by general perceptions surrounding genetic modification. Despite the capability of CRISPR to produce non-transgenic edits, scepticism and misinformation prevail, particularly in regions characterized by strong anti-GMO sentiment. Additionally, ethical debates concerning the ownership of genetic resources and the role of multinational corporations in shaping agricultural biotechnology further complicate the discourse surrounding genome editing in agriculture.

4. Intellectual Property and Access

The CRISPR-Cas system is embroiled in extensive patent disputes, which may restrict access for public-sector researchers and small-scale breeders, especially in developing countries. The absence of open-access frameworks

risks concentrating the benefits of CRISPR technology among a select few multinational corporations, potentially limiting the technology's equitable distribution and utilization.

5. Socio-Economic Disparities

The adoption of CRISPR technology necessitates advanced laboratory infrastructure, skilled personnel, and substantial financial investment, making it less accessible to resource-poor nations. There exists a pronounced risk that such technological inequalities could exacerbate global disparities in agricultural productivity and food security, further entrenching socio-economic divides.

6. Environmental and Ecological Concerns

The editing of stress-resistance and disease-resistance traits through CRISPR raises pertinent questions regarding long-term ecological impacts. For instance, there is a possibility that pathogens could evolve new virulence strategies to circumvent the resistance conferred by CRISPR-edited genes, thereby triggering an arms race, akin to that observed with pesticide resistance. Consequently, it is imperative to conduct rigorous ecological assessments before the large-scale release of CRISPR-edited crops to mitigate any adverse environmental consequences.

Conclusion and Future Outlook

CRISPR technology signifies a transformative advancement in agricultural innovation, providing precise, efficient, and relatively cost-effective methodologies for crop improvement. Its myriad applications, ranging from the enhancement of yield and resilience to the enrichment of nutritional content and the extension of shelf life, reveal its unprecedented potential for addressing global food security challenges. Empirical case studies involving staple crops such as rice, wheat, maize, tomato, soybean, and banana exemplify how genome editing can effectively tackle some of the most pressing issues faced in contemporary agriculture.

However, the journey toward the realization of this potential is fraught with significant challenges. Technical constraints, varied regulatory landscapes, and prevailing societal scepticism serve as considerable barriers to the widespread adoption of CRISPR technology in agriculture. Additionally, imperative considerations regarding equity arise, necessitating that the advantages conferred by CRISPR be accessible to smallholder farmers and developing nations, rather than becoming exclusive to technologically advanced regions.

In anticipating the future trajectory of CRISPR applications in agriculture, it is likely to be shaped by three pivotal trends: (i) the development of enhanced precision tools such as base editors and prime editing techniques, which aim to minimize off-target effects; (ii) the harmonization of international regulatory frameworks to streamline safe commercialization and facilitate trade; and (iii) the implementation of participatory approaches that actively involve farmers, consumers, and policymakers in the discourse surrounding technology deployment.

Through responsible stewardship and strategic engagement with these factors, CRISPR possesses the capacity to redefine the agricultural landscape, fostering a more productive, resilient, and sustainable agricultural system. Such a shift holds considerable promise for advancing food security and nutritional well-being for future generations, thereby addressing the critical needs of a growing global population.

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Integrated Pest Management (IPM): A Sustainable and Eco-Friendly Strategy for Insect Control in Crop Production Systems



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Abstract

Integrated Pest Management (IPM) is increasingly recognized as a sustainable and eco-friendly approach to insect control in crop production systems. Unlike conventional pest control methods that rely heavily on chemical pesticides, IPM integrates a combination of biological, cultural, mechanical, and chemical practices to maintain pest populations below economic thresholds while minimizing risks to human health, biodiversity, and the environment. This paper reviews the principles, strategies, and benefits of IPM in modern agriculture. It highlights the role of ecological balance, pest monitoring, and decision-making tools in reducing pesticide dependence and enhancing natural enemy populations. Emphasis is placed on case studies demonstrating successful IPM adoption, its contributions to food security, and its role in mitigating climate change impacts on pest dynamics. Challenges such as farmer awareness, policy support, and the need for cost-effective technologies are also discussed. The review concludes by underscoring the importance of research, innovation, and stakeholder participation in strengthening IPM adoption for sustainable crop production.

Keywords: Integrated Pest Management (IPM), Sustainable agriculture, Insect control, Biological control, Crop production, Eco-friendly strategies, Food security, Pest monitoring

1. Introduction

Agriculture, the backbone of global food security, faces an ever-growing challenge in ensuring adequate crop productivity while minimizing environmental degradation. Among the most pressing threats to agricultural production are insect pests, which account for substantial yield losses worldwide. Estimates suggest that between 20–40% of global crop production is lost annually to pests, leading to severe economic, environmental, and social consequences. Traditional pest control methods, primarily based on the intensive use of synthetic chemical pesticides, have undoubtedly played a pivotal role in increasing agricultural productivity during the Green Revolution. However, their indiscriminate and excessive use has triggered several ecological imbalances, ranging from pesticide resistance and pest resurgence to biodiversity loss, soil contamination, and human health hazards. This scenario necessitated the development of a more sustainable, eco-friendly, and economically viable strategy for pest management. Integrated Pest Management (IPM) emerged as a comprehensive solution, aiming not at the eradication of pests but at their management below economically damaging thresholds while maintaining environmental integrity. The Food and Agriculture Organization (FAO) defines IPM as “the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce risks to human health and the environment.”

IPM is, therefore, not a single tool or technique but a holistic approach that integrates biological, cultural, mechanical, genetic, and chemical methods, with decision-making based on economic thresholds and ecological principles. Unlike conventional pesticide-driven methods, IPM emphasizes prevention, monitoring, and the judicious use of control measures in a way that is compatible with natural ecosystems. The importance of IPM goes beyond pest management. It is deeply linked to the concept of sustainable agriculture, which emphasizes the long-term productivity of natural resources, the preservation of biodiversity, the reduction of carbon footprints,

and the protection of human health. As climate change, pesticide resistance, and food security challenges intensify, the relevance of IPM in modern crop production systems continues to expand. This research paper aims to provide a comprehensive overview of IPM as a sustainable and eco-friendly strategy for insect control. It explores the historical evolution, principles, eco-friendly components, field applications, challenges, and future prospects of IPM in diverse crop production systems.

2. Historical Evolution of Integrated Pest Management

The journey of pest management has undergone a remarkable transformation over centuries, evolving from traditional practices to modern, science-based integrated approaches. Understanding the **historical context of pest management** provides valuable insights into how IPM developed as a necessity for sustainable agriculture.

2.1 Traditional Pest Control Practices (Pre-20th Century)

In ancient agriculture, pest control strategies were primarily based on traditional and cultural methods derived from local knowledge. Farmers often relied on crop rotations, intercropping, trap crops, and natural predators to minimize pest incidence. For instance:

- Ancient Chinese farmers used predatory ants in citrus orchards as early as 300 AD.
- Indian farmers utilized Neem (*Azadirachta indica*) extracts for repelling pests, a practice still relevant in modern biopesticides.
- Indigenous communities often applied ash, plant extracts, and oils to deter insect pests.

Although these methods were environmentally friendly, they were often limited in efficacy and scale, particularly as agriculture intensified.

2.2 Advent of Synthetic Pesticides (1930s–1960s)

The discovery of synthetic chemical pesticides revolutionized agriculture during the mid-20th century. The introduction of DDT (dichloro-diphenyl-trichloroethane) in the 1940s was hailed as a breakthrough in pest control. These chemicals provided quick, broad-spectrum, and cost-effective control of insect pests, contributing significantly to the Green Revolution of the 1960s.

However, the honeymoon with pesticides was short-lived. Their overuse and misuse led to several unintended consequences:

1. Development of resistance in major insect pests.
2. Resurgence of secondary pests, previously suppressed by natural enemies.
3. Ecological imbalances due to the destruction of beneficial organisms.
4. Contamination of soil, water, and food with harmful residues.
5. Severe impacts on human and animal health.

Rachel Carson's seminal book, "**Silent Spring**" (1962), highlighted these adverse effects and marked a turning point in public awareness about the ecological hazards of pesticides.

2.3 Emergence of Integrated Pest Control Concepts (1950s–1970s)

The realization that reliance on chemical control alone was unsustainable led scientists to search for alternative approaches. The concept of "Integrated Control" was introduced in the 1950s by Stern et al. (1959), which emphasized the integration of chemical and biological control in a compatible manner. This idea laid the foundation for what later became Integrated Pest Management.

2.4 Global Adoption and Expansion of IPM (1980s–2000s)

The 1980s and 1990s witnessed rapid expansion of IPM programs across the globe. Many countries, including India, China, and the USA, implemented national IPM projects to reduce pesticide use and enhance environmental sustainability.

For example:

- In India, the National Integrated Pest Management Programme was launched in 1985, focusing on rice, cotton, pulses, and vegetables.
- In Indonesia, IPM policies were promoted in rice cultivation, where farmer field schools (FFS) trained farmers to adopt ecological pest management.
- In the USA and Europe, legislative frameworks and subsidies encouraged IPM adoption in fruit, vegetable, and field crops.

During this period, advances in biotechnology, pheromone technology, and microbial pesticides further strengthened the eco-friendly components of IPM.

2.5 IPM in the Era of Sustainable Agriculture (2000s–Present)

Today, IPM is recognized as a cornerstone of sustainable crop protection. Its scope has expanded from being a pest control strategy to a holistic approach aligned with climate-smart agriculture and food security goals. Modern IPM integrates:

1. Precision agriculture tools (remote sensing, drones, and IoT devices) for pest monitoring.
2. Biotechnological interventions, such as genetically modified crops resistant to specific pests.
3. Eco-friendly biopesticides, including microbial formulations, entomopathogenic fungi, and botanicals.
4. Agroecological practices, like conservation agriculture and habitat management, to support natural enemies.

As agricultural systems face the combined challenges of climate change, pesticide resistance, and biodiversity loss, the relevance of IPM as a sustainable and eco-friendly strategy is more

3. Principles of Integrated Pest Management

Integrated Pest Management (IPM) is guided by a set of **scientific principles** that prioritize prevention, ecological balance, and the judicious use of control measures. Unlike conventional approaches that rely heavily on chemical pesticides, IPM emphasizes a **systematic, knowledge-based framework**. The following are the core principles:

3.1 Prevention and Suppression

The primary goal of IPM is to **prevent pest outbreaks** rather than merely react to them. Preventive measures reduce the likelihood of pest build-up and minimize reliance on chemical interventions.

1. **Crop rotation:** Breaking pest cycles by alternating crops of different families.
2. **Resistant varieties:** Utilizing pest-resistant or tolerant crop cultivars.
3. **Soil health management:** Balanced fertilization and organic amendments that strengthen plant vigor and reduce susceptibility.
4. **Sanitation measures:** Removal of crop residues, volunteer plants, and alternate hosts.

3.2 Monitoring and Surveillance

Monitoring is the cornerstone of IPM. Accurate pest identification, assessment of population levels, and regular field observations help in **timely decision-making**.

1. **Field scouting:** Systematic sampling of crops to detect pest incidence.
2. **Use of pheromone and sticky traps:** Monitoring insect activity and population dynamics.
3. **Remote sensing and digital tools:** Use of drones, sensors, and mobile apps for pest surveillance.

3.3 Establishment of Economic Thresholds

IPM decisions are based on **Economic Threshold Levels (ETLs)** and **Economic Injury Levels (EILs)**, which help farmers decide when to apply control measures.

1. **Economic Injury Level (EIL):** The lowest pest density that causes economic damage.
2. **Economic Threshold Level (ETL):** The pest population level at which action must be taken to prevent reaching the EIL.

This ensures that interventions are applied **only when necessary**, preventing unnecessary costs and pesticide use.

3.4 Use of Multiple Control Strategies

IPM integrates a combination of **biological, cultural, physical, and chemical methods**. No single tactic is sufficient, and the combination ensures resilience and sustainability.

1. **Biological control:** Using predators, parasitoids, and pathogens.
2. **Cultural practices:** Crop rotation, trap cropping, and habitat management.
3. **Mechanical/physical control:** Traps, barriers, and manual removal.
4. **Chemical control:** Selective and judicious use of pesticides only when other measures fail.

3.5 Conservation of Natural Enemies

Beneficial insects such as ladybird beetles, spiders, parasitoid wasps, and predatory mites are natural regulators of pest populations. IPM emphasizes **habitat manipulation** and **avoidance of broad-spectrum pesticides** to conserve these beneficial organisms.

3.6 Farmer Education and Participation

Successful implementation of IPM requires **knowledge dissemination and capacity building**. Farmer Field Schools (FFS) and extension services empower farmers to make informed decisions about pest management.

4. Eco-Friendly Components of IPM

One of the defining features of IPM is its **eco-friendly orientation**, focusing on pest control strategies that minimize harm to the environment, biodiversity, and human health. The major eco-friendly components include:

4.1 Biological Control

Biological control is the **use of living organisms** (predators, parasitoids, and pathogens) to manage pest populations.

1. **Predators:** Ladybird beetles (Coccinellidae), lacewings (Chrysopidae), and spiders feed on aphids, caterpillars, and mites.
2. **Parasitoids:** *Trichogramma* spp. (egg parasitoids) are widely used against lepidopteran pests in cotton, rice, and sugarcane.
3. **Pathogens:** Microbial agents like *Bacillus thuringiensis* (Bt), entomopathogenic fungi (*Beauveria bassiana*), and viruses (NPVs – Nuclear Polyhedrosis Viruses) are effective against caterpillars and borers.

Biological control is cost-effective, environmentally benign, and self-sustaining once established.

4.2 Botanical Pesticides and Bio-Rational Products

Plant-derived compounds are widely used in IPM as alternatives to synthetic pesticides.

1. **Neem (Azadirachtin):** Acts as a repellent, antifeedant, and growth regulator.
2. **Pyrethrum (from Chrysanthemum flowers):** Used as a natural contact insecticide.
3. **Essential oils:** From garlic, eucalyptus, and citronella used as repellents.

4.3 Cultural Practices

Eco-friendly cultural practices are low-cost, farmer-friendly methods that reduce pest pressure.

1. **Crop rotation:** Disrupts pest life cycles.
2. **Trap cropping:** Planting small areas of highly attractive crops to lure pests away (e.g., mustard as a trap crop in cabbage fields).
3. **Intercropping:** Diversified cropping systems reduce pest colonization and spread.
4. **Timely sowing/harvesting:** Avoiding peak pest activity periods.

4.4 Mechanical and Physical Methods

These include direct, non-chemical interventions to suppress pest populations.

1. **Hand-picking:** Manual removal of egg masses and larvae.
2. **Light traps and pheromone traps:** Monitoring and mass trapping of moths.
3. **Sticky traps:** Controlling flying insects like whiteflies.
4. **Barriers and nets:** Protecting crops from insect invasion in nurseries and greenhouses.

4.5 Semiochemicals and Pheromones

Semiochemicals, such as sex pheromones, are used in pest management for:

1. **Monitoring:** Estimating pest population density.
2. **Mass trapping:** Attracting and capturing insects in traps.
3. **Mating disruption:** Saturating the environment with synthetic pheromones to prevent successful mating of pests.

4.7 Biotechnological and Modern Approaches

The integration of biotechnology has opened new eco-friendly possibilities in IPM.

- **RNA interference (RNAi):** Silencing essential pest genes.
- **Sterile Insect Technique (SIT):** Release of sterile males to suppress pest populations (successfully used in tsetse fly and fruit fly control).
- **Microbial consortia:** Combined use of bacteria, fungi, and viruses for synergistic pest suppression.

5. Challenges in Adoption of IPM

Despite its proven benefits, the widespread adoption of Integrated Pest Management faces several challenges. These are often linked to socio-economic, institutional, and technical barriers.

5.1 Lack of Awareness and Training

- Many farmers, especially smallholders, are unaware of IPM principles or lack access to training.
- Misconceptions persist that pesticides guarantee higher yields, leading to reluctance in shifting to IPM.
- Limited exposure to Farmer Field Schools (FFS) and extension programs hinders knowledge transfer.

5.2 Availability and Quality of Biocontrol Agents

- Mass production and distribution of biological control agents (e.g., *Trichogramma*, entomopathogenic fungi) remain inconsistent.
- Quality control issues (low viability, contamination) reduce farmer confidence.
- Lack of proper storage and transport facilities often limits access to remote areas.

5.3 Market and Policy Constraints

- Agrochemical companies aggressively market synthetic pesticides, making them more accessible than eco-friendly alternatives.
- In many countries, subsidies on pesticides distort farmer choices.
- Weak regulatory frameworks and inadequate support for biopesticides hinder IPM adoption.

5.4 Pest Resistance and Adaptation

- Over time, pests may develop resistance even to biopesticides and genetically engineered crops (e.g., Bt resistance in bollworms).
- Climate change alters pest behavior, making IPM implementation more complex.

5.5 Socio-Economic Barriers

- Smallholders may perceive IPM as labor-intensive and costly in the short term.
- Fragmented landholdings make community-level implementation difficult.
- Lack of financial incentives discourages adoption despite long-term benefits.

6. Future Prospects of IPM

The future of IPM lies in integrating **modern science, digital tools, and supportive policies** with traditional ecological knowledge. Its role will expand as agriculture faces growing challenges from climate change, pesticide resistance, and global food demand.

6.1 Digital and Precision Technologies

- **Drones and sensors** for real-time pest monitoring and mapping.
- **AI and machine learning models** for predicting pest outbreaks.
- **Mobile apps** to deliver pest advisory services to farmers.

6.2 Genomics and Biotechnology

- Use of **genome editing (CRISPR-Cas9)** to develop pest-resistant crop varieties.
- RNAi-based pesticides that silence essential pest genes with minimal off-target effects.
- Improved microbial biopesticides with enhanced persistence and field efficacy.

6.3 Policy Support and Incentives

- Governments can promote IPM through subsidies on biopesticides, training programs, and extension services.
- Stricter regulation of chemical pesticide use, especially broad-spectrum and highly hazardous ones.
- Support for Farmer Producer Organizations (FPOs) to implement IPM at a landscape scale.

6.4 Climate-Smart IPM

- Climate change is likely to increase pest pressure and spread invasive species.
- Climate-smart IPM will focus on **adaptive strategies**, such as adjusting planting dates, diversifying cropping systems, and enhancing resilience of natural enemies.

6.5 Integration with Sustainable Food Systems

- Growing consumer demand for pesticide-free and organic products offers market opportunities for IPM-grown crops.
- IPM will play a central role in ensuring compliance with **maximum residue limits (MRLs)** in global trade.

- Linking IPM to agroecology and regenerative agriculture will reinforce its role in sustainable food production.

10. Conclusion

Integrated Pest Management (IPM) has evolved as a cornerstone of sustainable agriculture, offering a balanced approach to crop protection that minimizes environmental degradation, enhances biodiversity, and safeguards human health. Unlike conventional pesticide-driven pest control, IPM integrates a variety of practices biological, cultural, mechanical, physical, and chemical based on ecological principles and economic thresholds.

The historical journey of IPM reflects humanity's gradual recognition of the limitations of pesticide reliance. From the early days of synthetic pesticides and the subsequent crisis of pest resistance and resurgence, to the ecological awareness ushered in by *Silent Spring* and the scientific refinement of integrated control, IPM has matured into a global strategy for pest management. Its principles of prevention, monitoring, and multi-pronged tactics ensure resilience against pest outbreaks while promoting long-term sustainability. The eco-friendly components such as biological control agents, botanical pesticides, resistant varieties, pheromones, and microbial formulations serve as alternatives to hazardous chemicals, aligning agricultural practices with environmental conservation goals.

However, challenges remain. Limited farmer awareness, inadequate supply of quality biocontrol products, policy biases towards chemical pesticides, and socio-economic barriers hinder widespread adoption. Yet, the **future prospects are highly promising**. Advances in biotechnology, genomics, digital agriculture, and climate-smart farming will further strengthen IPM. With stronger policy support, financial incentives, and participatory approaches like Farmer Field Schools, IPM can scale up from individual farms to landscapes, becoming a key pillar of food security.

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Comparative Evaluation of Soybean (*Glycine max* L.) Genotypes for Growth, Yield, and Adaptability under a Conservation Agriculture System



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Abstract

This study evaluated the performance of three soybean (*Glycine max* L.) genotypes under a conservation agriculture (CA) system, focusing on their growth, yield, and adaptability. We conducted a two-season field experiment using a randomized complete block design to compare Genotypes A, B, and C under no-till conditions with residue retention. Key parameters measured included plant height, number of pods per plant, seed index, and final grain yield.

Statistical analysis revealed significant genotypic variations ($P < 0.01$) for all parameters. Genotype B demonstrated a statistically significantly higher yield (3,550 kg/ha) compared to Genotype A (2,850 kg/ha) and Genotype C (3,100 kg/ha). This superior performance was linked to higher values in key yield components. Our findings underscore the crucial importance of selecting suitable genotypes for CA systems to optimize productivity and resource utilization efficiency. This research provides valuable insights for breeding programs and sustainable farming practices.

Introduction

The global agricultural sector is at a pivotal juncture, grappling with the dual challenges of meeting the dietary needs of a growing population while simultaneously mitigating the severe environmental consequences of conventional farming practices. For decades, intensive tillage has been the cornerstone of agricultural production, facilitating seedbed preparation and weed control. However, the long-term ecological and economic costs of this approach are now widely recognized. Continuous soil disturbance has been directly linked to a cascade of negative effects, including accelerated soil erosion, the loss of soil organic matter, disruption of beneficial soil microbial communities, and a significant contribution to atmospheric carbon dioxide levels through the oxidation of soil carbon. These factors not only degrade the land but also compromise the resilience and sustainability of agroecosystems, making them more vulnerable to climate variability and extreme weather events.

In light of these challenges, Conservation Agriculture (CA) has emerged as a scientifically robust and globally promoted alternative. CA is a holistic and sustainable land management system built on three interconnected principles: (1) minimal soil disturbance, typically achieved through no-tillage or reduced tillage; (2) permanent soil cover, which involves leaving crop residues on the soil surface; and (3) diversified crop rotations. This synergistic approach fundamentally alters the soil environment, fostering improved soil structure, enhanced water infiltration and retention, and increased biological activity. These changes contribute to greater resource use efficiency and can lead to more stable and resilient yields over time.

Soybean (*Glycine max* L.) is a critical component of global food and feed systems, and its integration into CA rotations is particularly beneficial. As a legume, soybeans' ability to fix atmospheric nitrogen through a symbiotic relationship with *Rhizobia* bacteria can reduce the dependency on synthetic nitrogen fertilizers, which are energy-intensive to produce and contribute to greenhouse gas emissions. However, the successful adoption of soybeans within CA systems is not without its complexities. The unique micro-environment created by no-tillage, characterized by higher surface residue, lower soil temperatures, and potentially higher moisture content, can influence crucial crop parameters such as emergence, root development, and nutrient uptake. Not all conventional soybean cultivars, which were bred for tilled systems, are equally suited to these conditions.

This research addresses a critical knowledge gap by conducting a detailed comparative evaluation of different soybean genotypes under a CA system. The study's primary objective is to identify superior cultivars that exhibit enhanced adaptability, robust growth, and higher yield potential in a no-till environment with residue retention. By analyzing key morpho-physiological and yield-related traits, we aim to provide valuable insights for plant breeders and agronomists. The findings will be instrumental in guiding the development of new soybean

varieties specifically tailored for CA, thereby accelerating the transition towards more sustainable, productive, and resilient agricultural systems.

Materials and Methods

A Randomized Complete Block Design (RCBD) with three replications was implemented to effectively control for spatial variability in soil properties. The three soybean genotypes under evaluation were: Genotype A, a well-established conventional high-yielding cultivar; Genotype B, a newly developed variety exhibiting a strong root system and purported drought tolerance; and Genotype C, a short-duration, early-maturing cultivar. Each experimental plot measured [5m x 4m], providing a sufficient area for data collection while minimizing edge effects. Seeds were sown at a uniform rate to achieve a target plant density, ensuring consistency across all plots.

1. Conservation Agriculture (CA) Management

The plots were managed under a strict conservation agriculture system. The core principles of CA were meticulously followed:

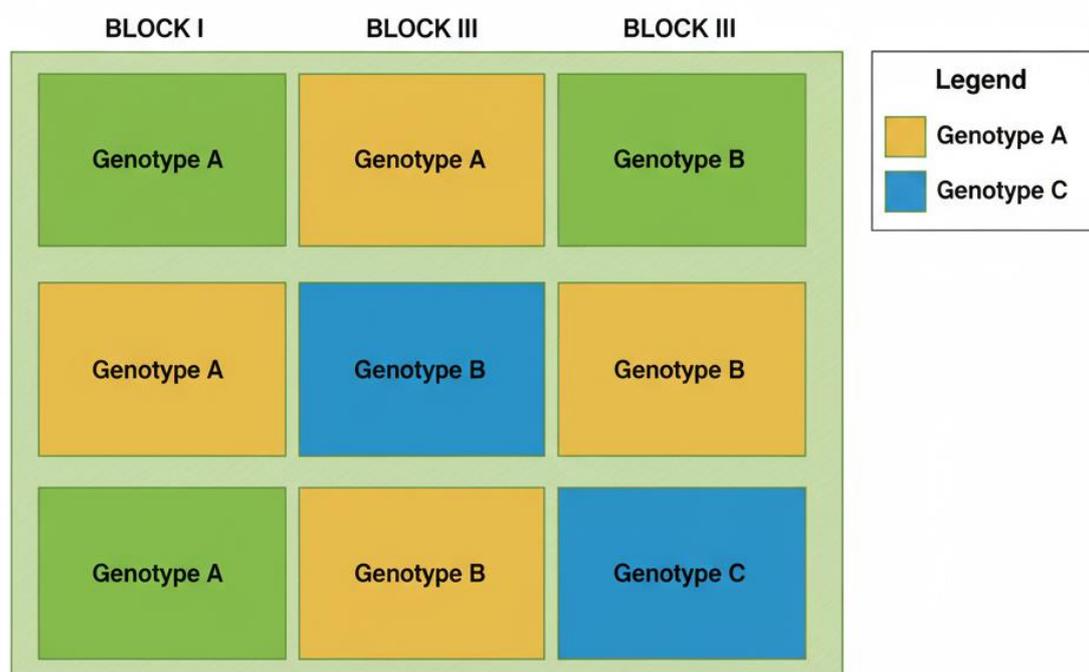


Figure 2. RCBRD Representation

- **No-Tillage:** All tillage operations were completely omitted. Planting was performed using a no-till planter designed to place seeds directly into the undisturbed soil.
- **Permanent Soil Cover:** Following the harvest of the preceding maize crop, all crop residues were left on the soil surface at an approximate load of [6 tons per hectare]. This residue layer served to protect the soil from erosion, suppress weed growth, and conserve soil moisture and temperature.
- **Crop Rotation:** The trial was part of a broader corn-soybean-wheat rotation, which is a key component of sustainable CA systems.

Nutrient management was based on comprehensive soil tests conducted before sowing. Phosphorus and Potassium were applied at recommended rates in a banded application to ensure nutrient availability. Given the soybean's nitrogen-fixing capability, no nitrogen fertilizer was applied to the crop. Weeds were managed using a combination of a pre-emergence herbicide [S-metolachlor] and a post-emergence herbicide [glyphosate], applied according to standard protocols for no-till systems.

2. Data Collection and Statistical Analysis

A detailed data collection protocol was followed to capture key physiological and yield-related parameters. At the R7 (physiological maturity) growth stage, a representative sample of ten plants was randomly selected from the central two rows of each plot to avoid border effects. The following measurements were taken:

- **Plant Height (cm):** Measured from the soil surface to the terminal bud of the main stem.
- **Pods per Plant:** The total number of pods with at least one viable seed was manually counted on each sampled plant.
- **Seed Index (g):** A random sample of 100 seeds from each plot's bulk harvest was weighed using a digital scale.

At harvest, a [e.g., 5 m²] area was mechanically harvested from the centre of each plot. The grain was threshed, cleaned, and weighed. A sub-sample was immediately analyzed for moisture content using a portable grain moisture meter. The final grain yield was then calculated and standardized to 13% moisture content, expressed in kilograms per hectare (kg/ha).

All data were analyzed using a two-way Analysis of Variance (ANOVA) with the statistical software [R software]. The model included genotype and block as independent variables. When the F-test indicated a significant difference at a probability level of $P < 0.05$, a post-hoc mean separation test, specifically Duncan's Multiple Range Test (DMRT), was applied to identify significant differences between the genotype means.

Results and Discussion

1. Growth and Yield Parameters

The analysis of variance (ANOVA) performed on the collected data revealed a highly significant effect of genotype ($P < 0.01$) on all measured parameters, including plant height, pods per plant, seed index, and final grain yield. This finding is crucial, as it indicates that the genetic makeup of the soybean cultivars played a dominant role in determining their performance under the specific conditions of the conservation agriculture (CA) system. The results underscore that not all genotypes are equally suited to this sustainable farming paradigm, reinforcing the importance of cultivar-specific selection.

As illustrated in Table 1, Genotype B consistently outperformed the other two genotypes across all measured parameters. Its plant height of 72.8 cm was significantly greater, suggesting a more vigorous growth habit and a potential advantage in light interception and biomass accumulation. The most compelling evidence of its superiority, however, was in the yield components. Genotype B produced an average of 61.5 pods per plant, a 27.6% increase over Genotype A and a 11.8% increase over Genotype C. This robust pod-setting capacity is a primary driver of high yield in soybeans. Furthermore, Genotype B also recorded the highest seed index, indicating not only an increased number of pods but also a superior ability to fill those pods with heavier, more developed seeds.

2. Yield Performance and Adaptability

The cumulative effect of these favourable traits was a statistically significant increase in final grain yield for Genotype B. At 3,550 kg/ha, its yield was approximately 24.6% higher than Genotype A and 14.5% higher than Genotype C. This robust performance is a strong indicator of its superior adaptability to the unique biophysical conditions of a CA system. The presence of crop residue and the absence of tillage create a soil environment that can be cooler and have higher moisture content in the topsoil. Genotype B's success may be attributed to a combination of physiological and morphological traits, such as an efficient root architecture that allows it to better access water and nutrients from the undisturbed soil profile, or a greater tolerance to the cooler soil temperatures during the critical germination and emergence phases.

Table 1 Mean Performance of Soybean Genotypes for Growth and Yield Traits under Conservation Agriculture

Trait	Genotype A	Genotype B	Genotype C	LSD (0.05)	P-value
Plant Height (cm)	65.4 ± 2.1 ^b	72.8 ± 1.9 ^a	68.1 ± 2.5 ^b	3.2	< 0.01
Pods per Plant	48.2 ± 3.5 ^c	61.5 ± 4.1 ^a	55.0 ± 3.8 ^b	4.8	< 0.01
Seed Index (g)	14.7 ± 0.8 ^b	15.9 ± 0.7 ^a	15.2 ± 0.9 ^{ab}	1.1	< 0.05
Grain Yield (kg/ha)	2,850 ± 120 ^c	3,550 ± 150 ^a	3,100 ± 130 ^b	215	< 0.01

Note: Values followed by the same letter in a row are not significantly different at $P < 0.05$ (Duncan's Multiple Range Test). ± represents the standard deviation.

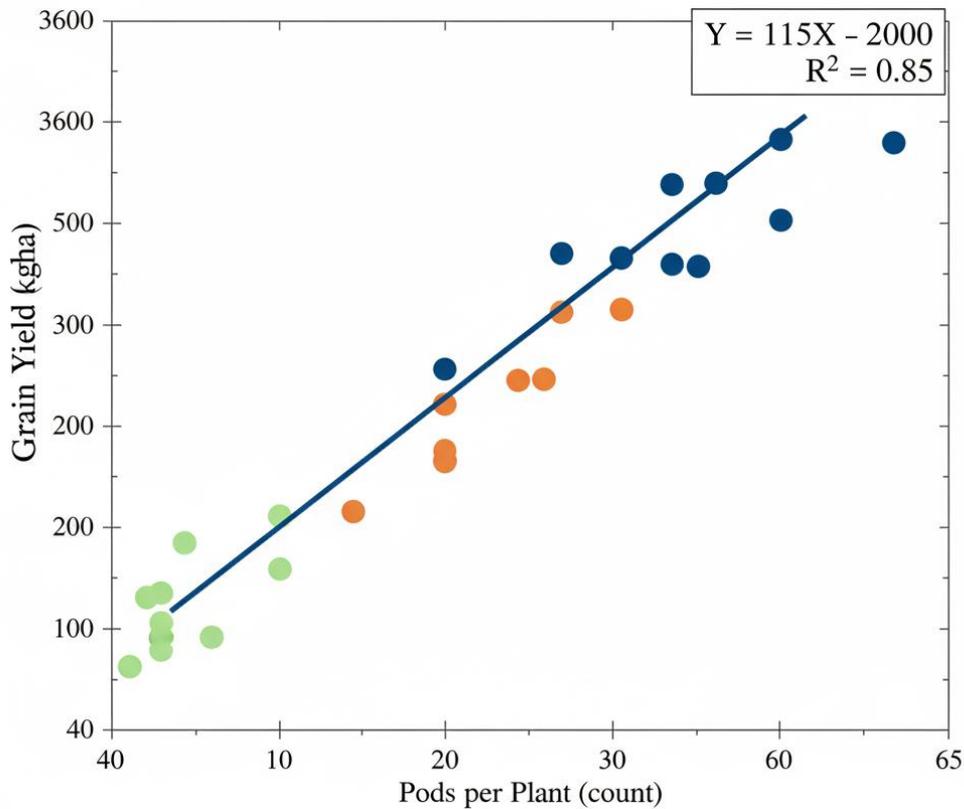


Figure 3. Positive linear Correlation between Pods per Plant and Grain Yield

The positive linear correlation between pods per plant and final grain yield, as shown in Figure 2, further highlights the significance of this specific trait in determining overall productivity. This finding aligns with established agronomic principles and confirms that pod number is a reliable indicator of yield potential in these genotypes. The enhanced performance of Genotype B in this study provides strong evidence that selecting cultivars with traits specifically suited for CA is essential for maximizing the benefits of this sustainable farming system. It also highlights the need for future breeding programs to actively select for these traits, rather than relying solely on cultivars developed for conventional agriculture.

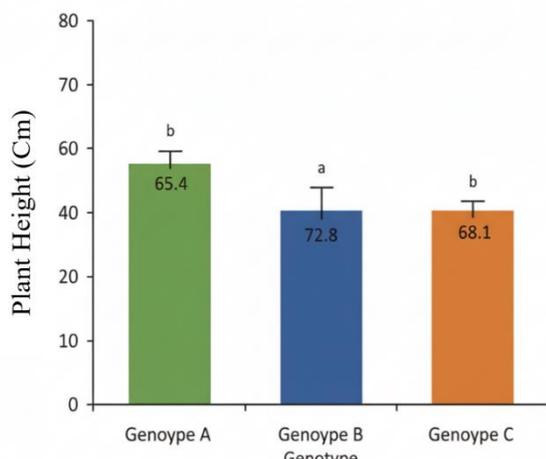


Figure 5. Mean Plant Height of Soyabean Genotype Under CA

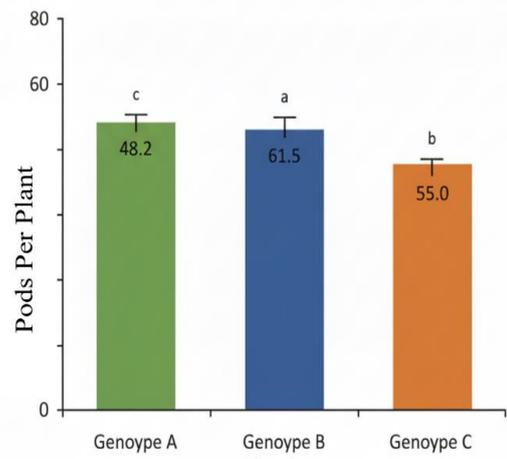


Figure 4. Pods Per Plant of Soyabean Genotypes Under CA

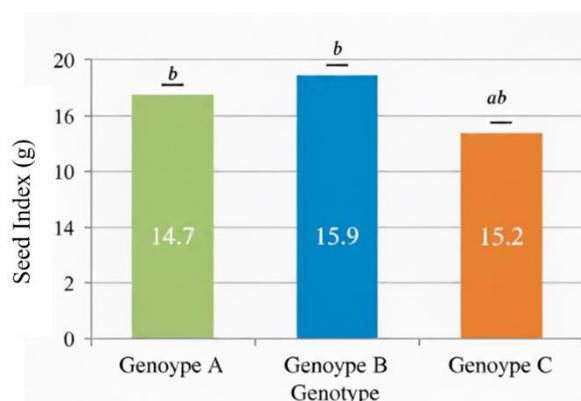


Figure 7. Mean Seed Index of Soyabean Genotypes Under CA

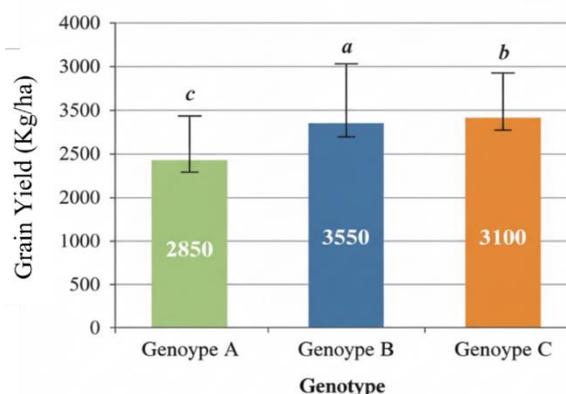


Figure 6. Mean Grain Yield of Soyabean Genotypes Under CA

Conclusion

The findings of this comprehensive study provide definitive evidence that the selection of an appropriate genotype is a pivotal determinant of soybean productivity and adaptability within a conservation agriculture (CA) system. Our comparative evaluation of three distinct cultivars unequivocally demonstrated significant inter-genotypic variation in growth, yield components, and final grain yield. Specifically, Genotype B emerged as the superior performer, exhibiting a statistically significant yield advantage that underscores its greater suitability for the unique biophysical conditions of no-tillage farming. This superior performance was directly correlated with its enhanced morpho-physiological traits, including a greater number of pods per plant and a heavier seed weight, which are key drivers of overall productivity. The observed positive relationship between pod number and yield highlights this trait as a primary target for future breeding efforts.

1. Implications for Sustainable Agriculture

The results of this research have profound implications for both academic research and practical farm management. For plant breeding programs, the data suggest a clear need to develop and screen new soybean genotypes specifically for traits that confer resilience and high performance in CA environments. This includes, but is not limited to, robust root systems for efficient nutrient and water uptake from the undisturbed soil, strong early-season vigor to overcome the cooler soil temperatures often associated with residue cover, and a high capacity for pod setting and grain fill. Relying solely on cultivars bred for conventional, tilled systems may lead to suboptimal outcomes in the context of sustainable agriculture, as these varieties may lack the necessary traits to thrive in no-tillage environments.

2. Future Research Directions

While this study provides a strong foundation, it also opens avenues for further investigation. Future research should explore the physiological and genetic mechanisms underlying the observed differences in genotypic performance. For instance, detailed studies on the root architecture of Genotype B could reveal how it efficiently navigates the denser, undisturbed soil profile. Additionally, molecular analysis could identify specific genes or quantitative trait loci (QTLs) associated with adaptability to CA, which would accelerate breeding for these desirable traits. Long-term studies are also needed to assess the cumulative effects of different genotypes on soil health and microbial communities within a CA system.

In conclusion, the successful and widespread adoption of conservation agriculture hinges not only on the implementation of its core principles but also on the strategic selection of crop cultivars that are genetically predisposed to thrive under these conditions. This research serves as a foundational dataset, highlighting the critical role of genotype-by-environment interactions and providing a strong scientific basis for guiding future breeding efforts toward the development of high-yielding, resilient, and resource-efficient soybean varieties for the future of sustainable agriculture.

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Pollinator Crisis: Challenges and Strategies for Global Food Security



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Introduction:

Pollinators represent a crucial element of global agricultural and ecological frameworks. Their role in facilitating the transfer of pollen between flowers is essential for the sexual reproduction of numerous plant species, thereby directly contributing to both crop productivity and the maintenance of biodiversity. Current estimates indicate that roughly 75% of the world's major food crops rely on animal-mediated pollination, which possesses an economic value estimated between \$235 billion and \$577 billion annually (FAO, 2019). In addition to enhancing human nutrition, pollinators play a fundamental role in sustaining ecosystems by promoting wild plant reproduction and fostering genetic diversity.

However, recent decades have witnessed a concerning trend: numerous scientific assessments indicate a significant decline in both the abundance and diversity of pollinator populations across various regions. This decline can be attributed to a multitude of factors, including habitat fragmentation, the pervasive use of pesticides, climate change, and the proliferation of diseases and parasites. Collectively, these stressors have placed pollinator populations in a precarious position, raising alarms not merely as an ecological challenge but as an emerging constraint on the resilience of global food systems. This is particularly pronounced in regions with economies that are heavily reliant on pollinator services for the production of horticultural and cash crops. Such declines pose threats not only to agricultural outputs but also to the stability of food security and biodiversity on a global scale.

Pollinators and Their Role in Agricultural Systems

Pollinators encompass a diverse array of organisms, including insects such as bees, butterflies, moths, flies, and beetles, as well as vertebrates like birds and bats, and, in certain geographic locales, even small mammals. Among these, bees are widely recognized as the most effective and economically significant pollinators due to their behaviours that facilitate the foraging of nectar and pollen, and their role in cross-pollination processes.

Globally, pollinators are indispensable for the productivity of a broad spectrum of crops. While staple cereals, including wheat, rice, and maize, primarily rely on wind for their pollination, a substantial proportion of fruit, vegetable, nut, and spice crops are either partially or wholly dependent on animal-mediated pollination. Numerous studies have demonstrated that the process of pollination not only augments crop yields but also enhances quality traits, such as size, shape, and nutritional content of fruits and seeds. These improvements in agricultural output contribute significantly to the overall sustainability and productivity of agricultural systems.

Moreover, pollinators play a critical role in supporting wild flora, thereby fostering genetic diversity and contributing to ecosystem resilience. This vital ecological service bears direct implications for food security, dietary diversity, and the livelihoods of rural communities. In regions such as South Asia, Sub-Saharan Africa, and Latin America, where smallholder farmers are reliant on pollinator-dependent crops for their subsistence and income, the decline of pollinator populations presents a considerable socio-economic challenge. The erosion of pollinator services in these areas could thus exacerbate existing vulnerabilities and undermine food systems that are already under stress from various factors, including climate change and market fluctuations.

Drivers of Pollinator Decline

The decline of pollinators represents a multifaceted phenomenon resulting from intricate interactions among various anthropogenic and environmental stressors. Recent scholarly evaluations have delineated several critical drivers contributing to this decline, outlined as follows:

1. Habitat Loss and Fragmentation

The processes of agricultural intensification, deforestation, and urban expansion have precipitated significant reductions in natural habitats, which are essential for providing adequate nesting sites and a diverse array of floral resources for pollinators. In particular, monoculture farming practices have led to large-scale losses of foraging resources, resulting in seasonal shortages that inhibit pollinator foraging behaviour and overall population viability.

2. Pesticide Exposure

The extensive application of chemical agents, including insecticides, fungicides, and herbicides, most notably neonicotinoids, has been robustly correlated with declines in pollinator populations. These chemicals interfere with critical behavioural functions, including navigation, memory, reproduction, and immune responses in bees. Moreover, chronic exposure to sub-lethal concentrations has been shown to adversely impact colony survival rates, further exacerbating the challenges faced by bee populations.

3. Climate Change

Shifts in climate parameters, particularly alterations in temperature and precipitation patterns, have profound implications for phenological dynamics, thereby disrupting the synchrony between flowering periods and pollinator activity. Such temporal mismatches can lead to reduced pollination efficiency and, potentially, diminished reproductive success in plant species. Furthermore, extreme weather events such as droughts, heatwaves, and storms have been observed to severely hinder pollinator activity and overall survival rates.

4. Pathogens and Parasites

Managed honeybee populations confront significant threats from a variety of pathogens, including microsporidian parasites such as *Nosema spp.* and various viral pathogens. Additionally, ectoparasitic infestations, most notably by the Varroa mite, continue to pose severe challenges. Wild pollinator species are likewise vulnerable to a spectrum of emerging diseases, many of which are transmitted via interactions with domesticated bee populations.

5. Pollution and Other Stressors

Environmental pollutants, such as air pollution, have been shown to disrupt floral scent trails, which are critical for the foraging success of pollinators. Moreover, light pollution can adversely affect nocturnal pollinators, including various species of moths. These factors, often overlooked in discussions regarding pollinator health, can significantly impair pollinator efficiency and enhance the challenges they face in foraging behaviour.

Case Studies of Pollinator Decline and Agricultural Impact

1. Almond Production in California, USA

California's Central Valley is responsible for producing nearly 80% of the global almond supply, a crop that is entirely reliant on insect pollination. To facilitate this, approximately 2 million managed honeybee colonies are annually transported to almond orchards, marking it as the largest annual pollination event worldwide. Nevertheless, the beekeeping industry faces significant challenges, as documented colony losses attributed to pesticide exposure, parasitic infestations, and inadequate forage diversity have escalated management costs. These issues raise substantial concerns regarding the long-term viability of pollination services critical to almond production.

2. Apple Orchards in Europe

Apples are among the most pollinator-dependent fruit crops in Europe, with studies conducted in the United Kingdom and Poland revealing the significant role of wild bee populations in enhancing fruit set and quality. These wild pollinators frequently complement the services provided by managed honeybee colonies. However, declines in wild pollinator populations attributable to habitat loss, pesticide use, and other factors have been associated with reduced yields and diminished fruit quality in certain regions. This trend underscores the economic risks that accompany the broader phenomenon of pollinator loss, particularly for fruit producers in Europe.

3. Coffee Cultivation in Latin America

Coffee, cultivated widely across Brazil, Colombia, and Central America, benefits substantially from bee pollination, which enhances both yield and bean size. Research has demonstrated that farms surrounded by diverse natural habitats host more pollinators, translating to 20–30% higher yields compared to monoculture systems. Deforestation and habitat degradation, however, threaten this synergy.

4. Mustard and Oilseed Crops in South Asia

In South Asian countries, such as India, mustard serves as a vital oilseed crop and is heavily reliant on insect pollination for successful production. The observed decline in honeybee populations, exacerbated by habitat loss and extensive pesticide application, has raised serious concerns regarding future agricultural productivity. Smallholder farmers, who typically lack access to managed pollination services and the financial resources to mitigate these issues, find themselves particularly vulnerable to the detrimental impacts of pollinator decline.

5. Global Perspective

A comprehensive meta-analysis conducted by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) in 2016 concluded that approximately 16.5% of vertebrate pollinators face threats of extinction globally. While regional declines in insect pollinators are increasingly documented, they often remain inadequately quantified. The agricultural ramifications of these declines are acutely felt in low- and middle-income countries, where food security and dietary diversity are heavily reliant on crops that depend on pollinators. The limited adaptive capacity of these regions exacerbates the vulnerability of their agricultural systems to the ongoing crisis of pollinator decline.

Conservation Strategies and Policy Responses

Given the multifaceted nature of pollinator decline, effective conservation strategies must comprehensively integrate ecological, agricultural, and socio-economic dimensions. A synergistic approach encompassing on-farm management practices, landscape-level planning, and policy interventions is imperative for mitigating risks and ensuring the sustainability of pollinator services.

5.1 Habitat Restoration and Floral Resources

The provision of continuous floral resources and suitable nesting habitats constitutes a foundational element of pollinator conservation. Implementing practices such as the establishment of hedgerows, flowering cover crops, and wildflower strips contributes to enhanced landscape heterogeneity, thereby supporting both managed and wild pollinator populations. Additionally, agroforestry systems, which promote the integration of trees and crops, offer critical habitats while simultaneously bolstering farm resilience.

5.2 Integrated Pest Management (IPM)

The adoption of Integrated Pest Management (IPM) is central to the protection of pollinators, particularly through the reduction of pesticide exposure. Alternatives to conventional pesticide use, such as biological control methods, selective pesticide application, and adherence to "bee-safe" spraying schedules, are essential strategies to minimize risks to pollinator health. Regulatory actions, exemplified by the partial restriction of neonicotinoids within the European Union, illustrate precautionary approaches to chemical management, reflecting the need for stringent oversight in this domain.

5.3 Sustainable Beekeeping Practices

The enhancement of honeybee colony health necessitates improved management practices targeting parasites, diseases, and nutritional stressors. Strategies such as breeding for disease-resistant bee strains, provision of supplemental forage, and the minimization of stress associated with long-distance colony transport are recommended. Moreover, the support of local and indigenous beekeeping practices can significantly bolster rural livelihoods while simultaneously contributing to the conservation of pollinator populations.

5.4 Policy and Global Initiatives

International frameworks, including the Convention on Biological Diversity (CBD) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), have acknowledged pollinator decline as a critical issue pertaining to biodiversity conservation. The adoption of National Pollinator Strategies in various countries, such as the United States, the United Kingdom, and India, demonstrates a commitment to coordinated actions across research, policy, and agricultural communities, promoting a holistic approach to pollinator protection.

5.5 Community Awareness and Citizen Science

The importance of public participation in pollinator conservation initiatives is increasingly recognized. Programs that encourage citizen-led monitoring of pollinator populations, the establishment of urban pollinator gardens, and educational campaigns serve to enhance public awareness and contribute valuable ecological data. Furthermore, engaging farming communities in participatory research fosters the adoption of pollinator-friendly practices, thereby promoting a collective effort to safeguard these essential ecological services.

Conclusion

Pollinators are fundamental to global agriculture, playing a critical role in enhancing both crop yields and the nutritional quality and diversity of human diets. It is estimated that approximately 75% of the world's flowering plants and a significant proportion of crops depend on animal pollination to reproduce effectively. These natural services not only contribute to agricultural productivity but also support the livelihoods of millions of farmers around the world. However, the alarming decline in pollinator populations, driven by factors such as habitat loss, pesticide exposure, climate change, and the emergence of diseases, presents significant risks to food security and the stability of ecosystems.

Empirical case studies from various regions highlight the profound economic and ecological repercussions associated with diminished pollination services, particularly within crops that exhibit high reliance on animal pollinators, such as fruits, vegetables, and nuts. For instance, a decline in bee populations has been directly linked to reduced yields of crops like blueberries and almonds, pointing to the critical interdependencies between pollinators and agriculture. In some areas, farmers have reported substantial economic losses due to the reduced presence of pollinators, underscoring the urgency of addressing this crisis.

To effectively combat these challenges, it is essential to adopt a holistic and collaborative approach that integrates agricultural management, ecological conservation, and comprehensive policy frameworks. Key strategies with proven efficacy include habitat restoration initiatives that create pollinator-friendly environments, the implementation of sustainable pest management practices that minimize pesticide use, and the optimization of beekeeping methodologies to support healthy bee populations. Furthermore, public education campaigns and community engagement in conservation efforts play a vital role in fostering awareness about the importance of pollinators and encouraging sustainable practices at the local level.

The role of policy cannot be underestimated; governments and international organizations must prioritize pollinator protection in agricultural policies, funding research initiatives, and promoting best practices that safeguard these vital species. Additionally, farmers can be encouraged to adopt agroecological approaches that enhance biodiversity on their farms, benefiting both pollinators and their own agricultural resilience.

Ultimately, the protection and preservation of pollinator populations is not merely an environmental necessity; it is also a socio-economic imperative that underpins the resilience of food systems for present and future generations. Restoring balance to these ecosystems is not just about ensuring the productivity of agricultural lands; it is about maintaining the natural processes that sustain life on Earth. In acknowledging and addressing the multifaceted challenges faced by pollinators, we pave the way toward a more sustainable and secure food future, protecting both our agricultural systems and the natural world from further decline. It is a shared responsibility that calls for immediate action, collaborative effort, and a commitment to preserving our planet's invaluable pollinators.

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Vertical Farming and Hydroponic Cultivation: Innovations in Controlled Environment Agriculture



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Introduction

In the heart of Tokyo, a former electronics manufacturing facility has been transformed into a vertical farm that yields thousands of heads of lettuce daily. Similarly, in New Jersey, agricultural operations are conducted within warehouse towers that utilize hydroponic systems, which require no soil. Meanwhile, on rooftops in Bengaluru, urban families cultivate their own salad greens using a minimalist setup comprising pipes, water, and essential nutrients.

This emerging paradigm of agriculture, characterized by vertical farming and hydroponics, represents a significant departure from traditional farming methods. As arable land diminishes, water resources become increasingly scarce, and urban populations swell with growing demands for food, these innovative agricultural practices offer potential solutions for sustainable food production in unconventional settings. Envision the prospect of cultivating lettuce within skyscrapers, ripening strawberries in repurposed shipping containers, or growing herbs on residential balconies, all achieved without relying on soil.

What has previously been perceived as speculative or visionary is now progressively evolving into a viable strategy for addressing the food security challenges of the future.

What Are Vertical Farming and Hydroponics?

Traditional agriculture has conventionally been characterized by the cultivation of crops in soil, illuminated by sunlight, and spread across expansive fields. However, vertical farming and hydroponics represent transformative approaches that fundamentally challenge these established norms.

Vertical farming is defined as the practice of growing crops in vertically stacked layers, rather than the horizontal spread typically associated with conventional farming. This method often utilizes controlled environments such as warehouses or glass towers where crops are cultivated in organized shelving units. By harnessing advanced technology, vertical farms maintain optimal growing conditions independent of external weather variables. This is achieved through the use of artificial lighting, often LED, which simulates sunlight and promotes photosynthesis, thereby facilitating year-round production.

Hydroponics, on the other hand, denotes a method of agriculture that omits soil as a growing medium altogether. In hydroponic systems, plants are nurtured in water solutions that are enriched with essential nutrients. Their roots may be supported through various methodologies, including suspension in nutrient-rich solutions (often referred to as aeroponics) or positioned within channels that allow for continuous flow of nutrient solutions.

The implications of these innovative farming techniques are profound. Crops cultivated in vertical farms and hydroponic systems have been shown to exhibit accelerated growth rates, significantly reduced water usage, and the capability to flourish in environments that would traditionally be unsuitable for agriculture, such as arid regions, densely populated urban settings, or even outer space.

In essence, while traditional agriculture may be likened to a natural orchestra harmonizing elements of soil, sunlight, and climate, vertical farming and hydroponics can be regarded as a sophisticated and technologically advanced system, orchestrating every aspect of the growing process to enhance yield and optimize resource efficiency.

Why the World Needs Vertical Farming and Hydroponics

The contemporary agricultural landscape is facing unprecedented challenges, driven by the projected increase of the global population, which is expected to exceed 9.7 billion by the year 2050. This demographic shift necessitates a dramatic escalation in food production, estimated at nearly 70% more than current levels.

Concurrently, the availability of arable land is diminishing, freshwater resources are depleting, and the unpredictability of climate change is exacerbating the risks associated with agricultural yields.

In this context, vertical farming and hydroponics emerge as transformative solutions to mitigate the pressing challenges of food production.

- **Shrinking Farmland:** Rapid urbanization has resulted in the encroachment of cities upon fertile agricultural land, thus limiting available space for traditional farming practices. Vertical farming presents a viable alternative by facilitating crop cultivation in controlled environments such as warehouses, rooftops, and skyscrapers, utilizing a substantially reduced physical footprint compared to conventional agriculture.
- **Water Scarcity:** The agricultural sector is a significant consumer of freshwater resources; however, hydroponic systems can reduce water utilization by as much as 90% when compared to traditional soil-based farming. This is primarily achieved through the recirculation of water, wherein nutrients are dissolved in water and delivered directly to plant roots, minimizing waste and enhancing water efficiency.
- **Climate Variability:** Increasing instances of extreme weather events, including droughts, floods, and heatwaves, have rendered outdoor farming increasingly precarious. Indoor vertical farms mitigate these risks by providing stable and controlled growing conditions year-round, thereby ensuring consistent and predictable crop yields independent of external climatic factors.
- **Food Miles:** The distance that produce travels from farm to consumer significantly contributes to the carbon footprint associated with food distribution. In many instances, a single head of lettuce may be transported hundreds of kilometres before reaching its destination. Vertical farming effectively reduces food miles by enabling the cultivation of fresh produce in close proximity to urban centres, consequently decreasing transportation costs and associated greenhouse gas emissions.
- **Health and Sustainability:** Vertical farming and hydroponic systems inherently minimize the need for harmful pesticides and provide precise control over nutrient delivery. This results in the production of cleaner, safer, and often nutritionally superior food products, ultimately contributing to public health and environmental sustainability.

Hydroponics vs Traditional Farming

Aspect	Hydroponics	Traditional Farming (Estimated)	Key Benefit
Water Usage per Kg Crop	4-10 L	80-100 L	Up to 90% water saving
Crop yield per acre	40-100 tons	18-25	Up to 50-100% more yield
Pesticide Use	Minimal	Moderate-High	Cleaner and safer produce
Labour requirement	Lower due to automation	High	Efficiency, Cost savings

Real-World Examples of Vertical Farming and Hydroponics

1. AeroFarms, USA

Situated in Newark, New Jersey, AeroFarms operates one of the world's largest vertical farms within a repurposed steel mill. Employing aeroponic technology, which involves misting plant roots with nutrient solutions rather than utilizing soil, the facility achieves a 95% reduction in water usage compared to traditional field farming. The growth cycle of their leafy greens is remarkably efficient, requiring only 12 to 14 days from germination to harvest, with products delivered to supermarkets within hours of being harvested.

2. Spread, Japan

Japan, constrained by limited agricultural land and a cultural preference for high-quality produce, has significantly adopted vertical farming practices. Spread's automated "Techno Farm" in Kyoto is capable of cultivating 30,000 heads of lettuce daily. This fully automated facility utilizes robotic systems for planting, harvesting, and packaging operations, resulting in a consistent supply of pesticide-free greens, independent of external weather conditions.

3. Rooftop Hydroponics in India

In major Indian metropolitan areas such as Bengaluru and Delhi, both startups and individual home gardeners are converting rooftops into hydroponic farming spaces. Utilizing basic materials, including PVC pipes, pumps, and nutrient solutions, these urban gardens allow families to harvest a variety of crops, including lettuce, spinach, strawberries, and herbs, directly from their terraces. Furthermore, local restaurants are increasingly sourcing produce from these urban hydroponic farms, thereby minimizing the complexity of supply chains.

4. NASA's Space Farming Experiments

In the context of space exploration, the absence of soil presents unique challenges for food production. To address this, NASA has been conducting research on hydroponics and aeroponics through its "Veggie" project aboard the International Space Station. This initiative has successfully yielded crops such as lettuce and zinnias, demonstrating the viability of soil-free agriculture and its potential application for sustaining human life on extraterrestrial bodies, including the Moon and Mars.

Challenges and Limitations

Despite the promising prospects of vertical farming and hydroponics, several significant challenges must be addressed before these methods can contribute to global food security at scale.

1. High Energy Demand

The photosynthetic requirements of plants necessitate artificial lighting, particularly in vertical farming operations. Typically, this results in the use of extensive banks of LED lamps that operate continuously. The associated electricity costs can be substantial, and if renewable energy sources are not employed, the resultant environmental impact may negate some of the sustainability advantages these systems purport to offer.

2. Expensive Setup Costs

The establishment of a climate-controlled vertical farming facility, equipped with pumps, sensors, and advanced lighting systems, entails considerable financial investment. This initial capital requirement presents a formidable barrier for small-scale farmers, particularly in developing countries, where access to such technology remains largely unattainable.

3. Crop Limitations

Current vertical and hydroponic farming practices predominantly focus on a limited range of crops, including leafy greens, herbs, and select fruits like strawberries. In contrast, staple crops such as rice and wheat, which collectively sustain billions of people, pose significant challenges for economic cultivation within these systems.

4. Technical Expertise Needed

The effective management of nutrient solutions, the maintenance of appropriate pH levels, and the operation of sophisticated technological equipment demand a high level of specialized knowledge. Consequently, farmers must receive training not only in agronomic principles but also in engineering and data management to ensure optimal operational efficacy.

5. Market Access and Affordability

Typically, produce cultivated hydroponically is sold at a premium price point. While this may be viable for urban middle-class consumers who are willing to pay extra for pesticide-free offerings, it limits access for lower-income households who require access to affordable staple foods.

6. Scale and Accessibility

To date, most successful vertical farming initiatives have been financially supported by large corporations or venture capital investments. The challenge remains to scale these models in a manner that effectively serves rural populations and smallholder farmers, thus ensuring broader accessibility to the benefits of vertical farming and hydroponics.

The Future of Vertical Farming and Hydroponics

Despite the persistent challenges associated with vertical farming and hydroponic systems, these innovative agricultural approaches are experiencing rapid expansion, facilitated by advancements in technology that are gradually reducing operational costs. The integration of renewable energy sources is addressing the significant electricity demands of these systems, while increasing levels of automation are enhancing operational efficiency continuously.

The potential future landscape for vertical farming and hydroponics may encompass several transformative developments:

- **Skyscraper Farms:** Envision the incorporation of high-rise structures within megacities, where each floor is dedicated to the cultivation of fresh vegetables, thereby providing immediate access to high-quality produce for the residents inhabiting those spaces.
- **Desert Farming:** Nations situated in arid regions, such as the United Arab Emirates and Saudi Arabia, are already committing substantial financial resources to the establishment of hydroponic farms. These investments serve to secure food supplies in environments characterized by harsh climatic conditions.
- **Everyday Access:** It is plausible that offices, educational institutions, and healthcare facilities will soon retrofit their environments with miniaturized agricultural systems. These installations could facilitate the direct provision of fresh food to canteens, thereby enhancing the nutritional quality available to staff and consumers.
- **Space Colonies:** Building on NASA's pioneering experiments aboard the International Space Station, there exists the potential for hydroponic systems to play a critical role in sustaining human life on extraterrestrial bodies, such as the Moon or Mars, thereby addressing the logistical challenges of food supply in space colonization efforts.

Closing Thought

For millennia, agriculture has been intrinsically linked to soil, sunlight, and expansive fields. However, the advent of vertical farming and hydroponics challenges these long-standing paradigms, demonstrating that food production need not be constrained by traditional agricultural practices. By vertically stacking crops and utilizing nutrient-rich solutions in lieu of soil, we can optimize agricultural output while significantly reducing the reliance on land, water and minimizing waste.

This approach does not seek to supplant conventional farming methods; rather, it aims to reinvent them, adapting them to meet the demands of a rapidly urbanizing world. The prospect of cultivating leafy greens in skyscrapers, ripening strawberries within shipping containers, and sourcing fresh produce from urban settings just blocks away from consumers is increasingly feasible.

What was once relegated to the realm of science fiction is swiftly transitioning into scientific reality. The implications of these innovations may be profound, serving as a pivotal component in addressing the food security needs of urban populations, contributing to sustainable practices on our planet, and even supporting human life in the exploration of extraterrestrial environments. As such, vertical farming and hydroponics represent not only a transformative shift in agricultural methodology but also a critical avenue toward achieving food resilience in the 21st century and beyond.

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Biometric Indices of Crop Growth



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Introduction:

Growth is an irreversible increase in mass, weight or volume of a living organism, organ or cell. Growth is an advancement towards maturity. It is the simplest index of plant growth; a rate of change in size, an increment in size per unit time. Plant growth indices refers to a set of concepts and equations by which changes in size of plants over time can be summarized and dissected in component variables. It is often applied in the analysis of growth of individual plants.

Growth analysis:

- Growth analysis is a mathematical expression of environmental effects on growth and development of crop plants.
- This is a useful tool in studying the complex interactions between the plant growth and the environment.
- This analysis depends mainly on primary values(dry weights) and they can be easily obtained without great demand on modern laboratory equipment.

Objectives of Growth Analysis :

- ❖ To know the rate of dry matter accumulation varies across the life cycle of the crop.
- ❖ To measure the daily performance of crop canopy.

Importance of growth indices:

- ❑ We can study the growth of the population or plant community in a precise way with availability of raw data on different growth parameters.
- ❑ These studies involve in assessment of the primary production of vegetation in the field *i.e.*, at the ecosystem level (at the crop level) of organization.
- ❑ The studies also provide precise information on the nature of the plant and environment interaction in a particular habitat.

Relative Growth Rate:

- ❖ This term was coined by Williams (1946).
- ❖ In plant physiology, RGR is a measure used to quantify the speed of plant growth.

Calculation:

$$RGR = \frac{\text{Loge } W_2 - \text{Loge } W_1}{t_2 - t_1}$$

Where, W_1 and W_2 are the plant dry weight at times t_1 and t_2 respectively.

units: g/g/day

Net assimilation rate:

- The concept was given by Williams (1946).

Calculation:

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\text{Loge } L_2 - \text{Loge } L_1}{L_2 - L_1}$$

Where, W_1 and W_2 are the plant dry weight at times, t_1 and t_2 respectively.

- L_1 and L_2 are the leaf area at times, t_1 and t_2 .

Units: g/m²/d.

Crop growth rate:

- It is the rate of growth of crop per unit land area.

- This method was suggested by Watson (1956)

Calculation:

$$CGR = \frac{W_2 - W_1}{t_2 - t_1}$$

W_1 and W_2 are the plant dry weight at times t_1 , t_2 .

Units: $g/m^2/day$

Specific leaf area (SLA):

- Specific leaf area is a measure of the leafiness of the plant on a dry weight basis. It was proposed by Kvet *et al.* (1971).

Calculation:

$$SLA = \frac{\text{Leaf area}}{\text{Leaf weight}}$$

Crop Equivalent Yield (CEY):

- In this, the yields of different intercrops are converted into an equivalent yield of anyone crop based on the price of the product

$$CEY = \frac{\text{Yield of test crop} + \text{Price of test crop}}{\text{Price of inter crop}} \times 100$$

Relative Yield Total (RYT):

- Used to determine a suitable combination of forage/pasture crops.

$$RYT = \frac{Y_{ab}}{Y_{aa}} + \frac{Y_{ba}}{Y_{bb}}$$

Where,

Y_{ab} = Yield of crop 'a' from unit area grown as intercrop

Y_{ba} = Yield of crop 'b' from unit area grown as intercrop

Y_{aa} = Yield of crop 'a' from unit area grown as sole crop

Y_{bb} = Yield of crop 'b' from unit area grown as sole crop

Land Equivalent Ratio (LER):

- Most frequently and efficiently used indicator.
- LER is the relative land area under sole crops that is required to produce the equivalent yield achieved in intercropping

$$LER = \frac{Y_{ab}}{Y_{aa}} + \frac{Y_{ba}}{Y_{bb}}$$

LER = <1 Disadvantageous, LER = 1 No profit, no loss, LER = >1 Advantageous

Monetary Advantage Index (MAI):

- It is a common practice of examining intercropping advantages by expressing yield in monetary term.

$$MAI = \frac{LER - 1}{LER} \times \text{Value of combined intercrops}$$

Relative Crowding Coefficient (RCC; K):

- It gives a measure of whether the species has produced more or less yield than expected.

$$K = \frac{Y_{ab} \times Z_{ba}}{(Y_{aa} - Y_{ab}) \times Z_{ab}}$$

Where,

Y_{ab} = Yield of species 'a' in association with species 'b'

Y_{aa} = Yield of species 'a' in pure stand

Z_{ab} = Sown proportion of species 'a' in association with species 'b'

Z_{ba} = Sown proportion of species 'b' in association with species 'a'

K = <1 yield disadvantageous, K = 1 no different, K = >1 yield advantageous

Aggressivity:

- It gives a simple measure of how much the relative yield increase in species "A" is go than that for species "B".

$$\text{Aggressivity} = \frac{\text{Mixture yield of crop A}}{\text{Expected yield of crop A}} - \frac{\text{Mixture yield of crop B}}{\text{Expected yield of crop B}}$$

Aggressivity = 0 both the species are equally competitive

Aggressivity = +ve - It means "A" species is dominant

Aggressivity = -ve - It means "B" species is dominant

Area Time Equivalent Ratio (ATER):

$$\text{ATER} = \frac{LA \times DA + LB \times DB}{T}$$

Where,

- LA and LB are relative yield or partial LERs of component crops A and B
- DA and DB are duration of crops A and B
- T is the total duration of intercropping system

ASSESSMENT OF LAND USE

Rotational Intensity (RI):

$$\text{RI (\%)} = \frac{\text{Number of crops grown in rotation}}{\text{Duration of rotation}} \times 100$$

Cropping Index (CI):

$$\text{CI (\%)} = \frac{\text{Number of crops grown per annum}}{\text{Given area of land}} \times 100$$

Land Utilization Index (LUI):

- It is defined as the number of days during which the crops occupy the land during a year divided by 365 and can be expressed as a fraction or as a percentage.

$$\text{LUI} = \frac{\text{No. of days for which land is utilized in a year}}{365}$$

Cultivated Land Utilization Index (CLUI):

$$\text{CLUI} = \frac{\text{No. of crop days} \times \text{area}}{365 \times \text{net area}}$$

Harvest Index:

- Economic yield is the amount of productivity which is partitioned into the useful or harvested portion of the crop

$$\text{HI (\%)} = \frac{\text{Economic yield (kg/ha)}}{\text{Biological yield (kg/ha)}}$$

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BIOTECHNOLOGY: A MODERN TOOL FOR FRUIT PRODUCTION



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Abstract

Fruit production is a cornerstone of global agriculture, providing nutrition, economic security, and livelihood to millions of farmers worldwide. With the world population rising steadily, the demand for fruits has increased dramatically. Conventional breeding techniques, though valuable, often face limitations such as long juvenile periods, sterility, and cross-incompatibility. Biotechnology has emerged as a game-changing solution by offering advanced tools such as tissue culture, micropropagation, somaclonal variation, embryo rescue, molecular markers, and genetic transformation. These technologies enable faster development of high-yielding and stress-resistant cultivars while ensuring disease-free planting material. Practical applications include disease-resistant papayas, seedless grapes, long-shelf-life bananas, and virus-free strawberries. This article explores the different biotechnological tools in fruit production, their impact on global horticulture, and the opportunities they present for building a sustainable fruit industry in the future.

Keywords: Fruit biotechnology, tissue culture, embryo rescue, molecular markers, somaclonal variation, genetic transformation, sustainable horticulture

Introduction

Fruits are not just a source of vitamins and minerals but also play a vital role in human health, trade, and national economies. In many developing countries, fruit cultivation contributes significantly to rural income and employment. However, producing enough fruits to meet both local and global demand is challenging. Conventional breeding methods—such as hybridization, grafting, and selection—have contributed greatly to crop improvement, but they often fall short due to biological barriers. For instance, fruit crops like mango and apple have long juvenile periods, sometimes taking 5–7 years to bear fruit. Similarly, many crops face sterility or incompatibility issues that make traditional crossbreeding difficult (Anuradha *et al.*, 2017). Moreover, climate change, pests, and diseases continue to threaten yields.

Biotechnology offers solutions to these challenges by integrating modern molecular and cellular techniques into fruit breeding. It allows scientists to bypass natural reproductive barriers, produce uniform and disease-free planting material, and introduce traits such as drought tolerance, disease resistance, and improved shelf life. In short, biotechnology is not just an alternative—it is becoming an essential tool for the future of fruit cultivation.

Major Biotechnological Tools in Fruit Production

1. Tissue Culture and Micropropagation

Tissue culture is one of the most widely used methods in horticulture. By culturing tiny plant parts (like shoot tips or meristems) under sterile conditions, millions of genetically identical, disease-free plants can be produced.

- **Banana:** Today, nearly all commercial banana plantations rely on tissue culture to combat Banana Bunchy Top Virus (BBTV). Tissue culture ensures fields are planted with disease-free stock, reducing losses and increasing productivity.
- **Strawberry:** This was one of the first fruits where micropropagation was standardized. Tissue culture strawberries produce higher yields, more uniform runners, and improved survival rates compared to traditional propagation (Sharma and Singh, 1999; Kikas *et al.*, 2006).



- **Citrus:** Shoot-tip grafting in citrus has been successful in producing virus-free plants, securing healthier orchards.

Beyond propagation, **synthetic seed technology**—where small plant tissues are encapsulated and stored—now enables easier transport and conservation of elite germplasm worldwide.

2. Embryo Rescue

In many fruit crops, hybrid embryos fail to develop naturally due to incompatibility. Embryo rescue is a technique where immature embryos are grown in the lab, allowing plant breeders to create new hybrids that would otherwise be impossible.

- **Grapes:** This method has been crucial in producing seedless grape varieties such as *Sweet Scarlet* and *Thomcord*. These seedless hybrids were developed by rescuing embryos from incompatible crosses (Anonymous, 2004).
- **Other Fruits:** Embryo culture also helps speed up breeding in long-duration crops like mango and citrus, where normal seed development is slow or hindered.

This tool essentially gives scientists a shortcut to overcome barriers of nature.

3. Somaclonal Variation and In Vitro Mutagenesis

When plants are grown in tissue culture, genetic variations sometimes appear. While this was once considered a disadvantage, breeders now see it as an opportunity to create useful diversity.

- **Banana:** Mutagenesis using gamma rays produced the variety *Novaria*, which has early flowering and longer shelf life (Mac *et al.*, 1996). Another famous example is GCTCV-119, a somaclonal variant resistant to Fusarium wilt.
- **Peach and Apple:** Somaclonal variants with resistance to bacterial leaf spot and fire blight have been identified, offering farmers more resilient orchards (Hammerschlag *et al.*, 1994; Donovan *et al.*, 1994).

In vitro mutagenesis using radiation or chemicals speeds up the creation of new traits compared to traditional mutation breeding.

Table 1. Stability of some somaclones to biotic stresses under field condition

Fruit crop/cultivar	Somaclonal variant	Resistant/tolerant to	Field performance	Reference
<i>Prunus persica</i> (Sunhigh, Redhaven)	S19-1, S156, S122-1	Bacterial leaf spot (<i>Pseudomonas syringae</i>)	High resistance after 3 yrs	Hammerschlag <i>et al.</i> , 1994
Apple cv. Green Sleeves	-	Fire blight (<i>Erwinia amylovora</i>)	60% less symptoms	Donovan <i>et al.</i> , 1994
<i>Citrus limon</i>	FS 01, FS 11	Mal Secco (<i>Phoma tracheiphilla</i>)	Tolerance comparable to 'Monachello'	Gentile <i>et al.</i> , 1998
Banana cv. Williams	CIEN BTA-03	Yellow and black Sigatoka	Stable performance after 5 yrs	Unai <i>et al.</i> , 2004

4. Somatic Hybridization

Some crops are nearly impossible to cross naturally due to genetic incompatibility. Somatic hybridization solves this by fusing two somatic (body) cells from different species or varieties to produce hybrids.

- **Citrus:** After decades of research, somatic hybrids have been created to improve both rootstocks and scions. These hybrids combine traits like dwarfing (important for high-density planting), disease resistance, and seedlessness (Grosser *et al.*, 2000).

This technology helps breeders combine traits across species boundaries, opening up entirely new possibilities.

5. Molecular Markers and Genetic Diversity

Molecular markers are DNA-based “tags” that allow breeders to identify traits without waiting for plants to mature.

- **Sex Identification:** In crops like date palm and papaya, where plants take years to show their sex, molecular markers allow early identification of female plants, saving time and resources (Dhawan *et al.*, 2013; Dwivedi *et al.*, 2014).
- **Disease Resistance:** Markers linked to traits like nematode resistance in grapes or scab resistance in apples are already used in breeding programs (Xu *et al.*, 2008).
- **Diversity Studies:** DNA markers also help assess genetic diversity, guiding the conservation and improvement of fruit crops such as mango, citrus, and cashew.

Table 2. DNA markers for genetic diversity assessment in fruit crops

Fruit	Marker type	Reference
Apple	AFLP, RAPDs	Coart <i>et al.</i> , 2003; Sestras <i>et al.</i> , 2009
Avocado	Mini-satellite DNA	Ashworth <i>et al.</i> , 2003
Banana	RAPDs	Brown <i>et al.</i> , 2009
Citrus	RFLP	Durham <i>et al.</i> , 1992
Grapes	RFLP, SSRs	Bourquin <i>et al.</i> , 1993
Mango	cpSSR, RAPDs	He <i>et al.</i> , 2007; Marcela <i>et al.</i> , 2009
Pistachio	Mini-satellite marker	Riaz Ahmad <i>et al.</i> , 2003
Cashew	RAPD, ISSR	Thimmappaiah <i>et al.</i> , 2009
Pear	SSRs, AFLP	Sisko <i>et al.</i> , 2009

Table 3. Markers associated with main polygenic traits in fruit crops

Fruit	Trait	Marker type	Reference
Apple	Fire blight resistance	SCAR, SSR	Sylwia <i>et al.</i> , 2009
Citrus	Citrus leprosis virus resistance	AFLP, RAPD	Bastianel <i>et al.</i> , 2009
Pear	Incompatibility	AFLP, SSR	Sun <i>et al.</i> , 2009
Banana	Sugar content	RFLP	Ming <i>et al.</i> , 2001
Grapes	Seedlessness, berry size, ripening date	AFLP, SSR, RAPD, ISSR, SCAR	Mejía <i>et al.</i> , 2007
Strawberry	Day-neutrality	AFLP	Weebadde <i>et al.</i> , 2008
Apricot	Plum pox virus resistance	SSR	Soriano <i>et al.</i> , 2007

6. Genetic Transformation and Transgenic Fruits

Genetic transformation involves inserting desirable genes into plant cells using techniques such as **Agrobacterium-mediated transformation**, **particle bombardment (gene gun)**, **electroporation**, or **RNA interference (RNAi)**. These approaches allow scientists to directly transfer traits like disease resistance, stress tolerance, or delayed ripening into fruit crops.

- **Papaya:**
The transgenic cultivars *Rainbow* and *Sun Up* were developed using **Agrobacterium-mediated transformation**. The coat protein gene of papaya ring spot virus (PRSV) was inserted, providing resistance and rescuing Hawaii's papaya industry (Gonsalves, 2000).
- **Plum:**
The *Honey Sweet* plum, resistant to Plum Pox Virus (PPV), was developed using **Agrobacterium-mediated transformation combined with RNAi silencing**. The PPV coat protein gene fragment triggered gene silencing, preventing viral replication (Ravelonandro *et al.*, 2000).
- **Banana:**
Transformation in banana uses **Agrobacterium-mediated transformation** and **particle bombardment**. Ripening-related genes such as *MaMADS-rin* and *MaExp2* have been modified using

RNAi technology, leading to delayed ripening and extended shelf life (Liu *et al.*, 2009; Tomer *et al.*, 2016).

- **Strawberry:**

In strawberries, transformation is mainly done through **Agrobacterium-mediated transformation** of leaf discs or tissue-cultured explants. Genes such as *polygalacturonase* and *sucrose synthase* have been downregulated using **RNAi silencing**, delaying softening and extending shelf life (Juan *et al.*, 2009; Cheng *et al.*, 2017).

- **Citrus:**

Transformation in citrus employs both **Agrobacterium-mediated techniques** and **protoplast electroporation**. Genes for resistance to citrus tristeza virus and other pathogens have been tested, showing potential for future commercial varieties (Grosser *et al.*, 2000).

Transgenic papaya varieties



Two varieties of papaya resistant to papaya ringspot virus have been developed using biotechnology: SunUp, left, and Rainbow, right. They have performed well for Hawaiian growers, even under prolonged and heavy disease

Figure 1. Transgenic papaya varieties (Sunup and Rainbow)



Figure 2. Arctic apple showing resistance to browning



Figure 1. Plum showing plum pox virus symptoms and honey sweet plum variety resistant to plum pox virus

Future Prospects

The future of fruit production lies in the integration of biotechnology with precision farming, genomics, and climate-smart agriculture. Potential advancements include:

- **Stacking Multiple Traits:** Developing fruit varieties that are simultaneously drought-tolerant, pest-resistant, and high-yielding.
- **CRISPR Gene Editing:** Precise genome editing tools like CRISPR are opening new frontiers for creating improved fruits without introducing foreign DNA, which could increase public acceptance.
- **Nutritional Enhancement:** Bio-fortified fruits with higher levels of vitamins, antioxidants, or nutraceuticals could address malnutrition.
- **Conservation of Rare Germplasm:** In vitro conservation and cryopreservation will help preserve rare and endangered fruit species for future use.

However, challenges remain. Consumer concerns about genetically modified organisms (GMOs), regulatory hurdles, and biosafety assessments must be addressed carefully. Transparent communication and responsible application will be key to ensuring biotechnology's success in horticulture.

Conclusion

Biotechnology is transforming fruit production by offering solutions to age-old challenges faced by traditional breeding. From virus-resistant papayas in Hawaii to high-yielding bananas across Asia, the benefits are already visible. Techniques such as tissue culture, embryo rescue, somatic hybridization, molecular markers, and genetic transformation are enabling faster, more efficient, and more sustainable crop improvement.

As the world grapples with climate change, food insecurity, and increasing demand, biotechnology stands out as a powerful ally in building resilient fruit systems. With continued research and responsible application, the fruits of tomorrow will be not only more abundant but also healthier, safer, and longer-lasting.

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Impact of Changing Climate on Jute Cultivation: Challenges and Mitigation



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Introduction:

Jute, often referred to as the “golden fiber” is one of the most important natural fibers after cotton. It plays a significant role in the agrarian economy of countries like India and Bangladesh, which together account for over 90% of the global jute production. Cultivated primarily in warm and humid climates, jute thrives in regions with annual rainfall of 1500-2000 mm, temperatures between 24-35 °C and well drained alluvial soils.

In recent decades, however, the global climate has been changing at an unprecedented pace due to anthropogenic activities. Alterations in rainfall distribution, rising temperatures, increased frequency of floods and droughts, and shifting pest disease dynamics have posed serious threats to sustainable jute cultivation. This chapter explores how these climatic changes impact jute production systems, fiber quality, and farmer livelihoods, while also outlining adaptive strategies.

Climate Change Trends in Jute Growing Regions:

- ❖ **Rising Temperatures:** Average temperatures in Eastern India and Bangladesh have shown a consistent increase of 0.5-1 °C over the last few decades, leading to higher evapotranspiration and soil moisture stress.
- ❖ **Erratic Rainfall:** While jute requires abundant water, extreme variability in monsoon patterns has resulted in prolonged dry spells as well as intense floods.
- ❖ **Increased Frequency of Extreme Weather Events:** Cyclones, flash floods, and unseasonal rainfall events are becoming more common in jute growing belts.
- ❖ **Soil and Water Stress:** Waterlogging and salinity, induced by climatic anomalies, reduce soil productivity and fiber yield.

Impacts on Jute Cultivation:

- ❖ **Effects on Crop Growth and Yield:**
 - ✓ **Temperature Stress:**
Elevated temperatures during germination reduce seed viability and seedling vigor. Prolonged heat stress during the vegetative phase leads to stunted growth, reduced branching and lower biomass accumulation.
 - ✓ **Rainfall Variability:**
Drought conditions during sowing delay crop establishment, while excessive rainfall and waterlogging during growth stages increase susceptibility to root and stem rot diseases.
 - ✓ **Flooding:**
Inundation beyond 3-5 days results in plant mortality, especially in sandy loam soils.
- ❖ **Fiber Quality Degradation:**
 - ✓ Higher temperatures during retting accelerate microbial activity but often lead to uneven retting, causing coarse and brittle fibers.
 - ✓ Water scarcity during retting seasons forces farmers to use stagnant, polluted water, resulting in poor fiber color and strength.

❖ **Pest and Disease Dynamics:**

- ✓ Warmer and more humid conditions have led to an upsurge of stem rot (*Macrophomina phaseolina*), soft rot (*Sclerotium rolfsii*) and insect pests such as jute hairy caterpillar (*Spilarctia obliqua*).
- ✓ Climate driven changes in pathogen life cycles and vector populations increase the frequency and severity of outbreaks.

❖ **Socioeconomic Consequences:**

- ✓ Unpredictable yields and poor quality fibers directly affect farmer income and market stability.
- ✓ Marginal farmers, who depend solely on monsoon rains, are most vulnerable to climate induced risks.
- ✓ Migration and livelihood diversification have become coping strategies in severely affected areas.

Challenges and Mitigation Strategies in Jute Cultivation under Changing Climate:

Challenges	Mitigation Strategies
Erratic rainfall & floods	<ul style="list-style-type: none"> • Raised bed planting and drainage channels. • Community rainwater harvesting. • Flood tolerant jute varieties
Drought & heat stress	<ul style="list-style-type: none"> • Drought tolerant and short-duration varieties. • Mulching and conservation tillage • Supplemental irrigation using harvested water
Pest & disease outbreaks	<ul style="list-style-type: none"> • Integrated Pest Management (IPM) with bio-agents (<i>Trichoderma</i>, <i>Pseudomonas</i>) • Timely monitoring and need based pesticide use • Resistant/tolerant cultivars
Fiber quality decline (poor retting water)	<ul style="list-style-type: none"> • Microbial retting (e.g., <i>CRIJAF SONA</i>) • Tank and ribbon retting methods • Development of community retting ponds
Socioeconomic vulnerability of small farmers	<ul style="list-style-type: none"> • Crop insurance and risk coverage schemes • Minimum Support Price (MSP) assurance • Access to low interest credit and input subsidies
Lack of infrastructure & policy support	<ul style="list-style-type: none"> • Creation of retting friendly infrastructure • Mechanization support for sowing/harvesting • Strengthened extension services & ICT based advisories
Knowledge & skill gaps	<ul style="list-style-type: none"> • Farmer training on climate smart practices • Field demonstrations through KVKs and research stations • Mobile based weather and agro advisories

Adaptive Strategies for Sustainable Jute Cultivation:

❖ **Crop and Variety Improvement:**

- ✓ **Development of Climate Resilient Varieties:** Breeding programs should focus on drought tolerant, flood tolerant and disease resistant jute genotypes.
- ✓ **Seed Technology:** Use of high germination, certified seeds can help maintain crop establishment under erratic climatic conditions.

❖ **Improved Agronomic Practices:**

- ✓ **Water Management:** Adoption of raised bed planting, field channels and community water harvesting structures to combat droughts and floods.
- ✓ **Soil Health Management:** Application of organic matter and microbial inoculants to improve soil structure, resilience and disease suppression.
- ✓ **Integrated Nutrient and Pest Management (INM/IPM):** Combining biological controls with judicious use of chemicals to reduce crop losses.

❖ **Retting Innovations:**

- ✓ **Microbial Retting:** Use of consortia like *CRIJAF SONA* enhances retting efficiency and fiber quality even under low water conditions.

- ✓ **Tank and Ribbon Retting:** Alternatives to traditional water retting, these methods conserve water and reduce dependence on fluctuating river systems.
- ❖ **Climate Smart Extension Services:**
 - ✓ **Weather Based Agro Advisories:** Dissemination of timely forecasts and advisories to farmers.
 - ✓ **Capacity Building:** Training farmers in climate resilient practices and diversification strategies.
 - ✓ **Insurance Schemes:** Promoting crop insurance to reduce financial vulnerability.

Research and Policy Perspectives:

- ❖ **Agro-climatic Modeling:** Predicting climate change impacts on jute productivity and devising region-specific adaptation frameworks.
- ❖ **Carbon Footprint of Jute Systems:** Promoting jute as an eco-friendly fiber in global markets while addressing its cultivation vulnerabilities.
- ❖ **Policy Support:** Government interventions in providing irrigation facilities, credit, minimum support prices, and retting infrastructure.
- ❖ **International Collaboration:** Sharing knowledge and technologies between India, Bangladesh and other jute growing countries.

Conclusion:

Climate change poses a multifaceted challenge to jute cultivation, threatening both production and quality. Rising temperatures, erratic rainfall and increased pest disease pressures have already begun to reshape the agro ecology of traditional jute belts. Yet, the resilience of the jute sector lies in adopting innovative technologies, improved crop management practices, and robust policy frameworks. Strengthening climate resilient strategies not only secures the livelihoods of millions of jute farmers but also safeguards the future of this sustainable natural fiber in a changing world.



Impact of Innovative Nutritional Approaches on Livestock Health, Productivity and Welfare



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Introduction

Livestock production underpins global food security and rural livelihoods, supplying essential nutrients (proteins, energy, minerals and vitamins), income and employment to billions of people. Yet the sector faces unprecedented challenges, including growing demand for animal-source foods, climate change pressures and environmental sustainability targets and rising societal expectations for animal welfare. At the same time, the threat of antimicrobial resistance (AMR) underscores the urgent need to reduce reliance on antibiotics for growth promotion and disease prevention. These pressures are driving a paradigm shift in how livestock are fed and managed. Nutrition is no longer seen merely as a means of meeting energy, protein, minerals and vitamins' requirements but as a strategic tool to enhance animal health, productivity and welfare while reducing environmental footprints.

Innovative nutritional approaches are emerging at the forefront of this transformation. Precision feeding and digital nutrition harness sensors, data analytics and algorithms to match diets more closely with animals' physiological needs, reducing nutrient wastage, improving feed efficiency and enabling early detection of health disorders. Such systems also contribute to welfare by minimizing competition for feed and preventing metabolic stress. In parallel, microbiome-targeted strategies, including probiotics, prebiotics, phytochemicals and organic acids, are providing natural alternatives to antibiotic growth promoters. These additives have been shown to improve gut health, immunity and resilience, thereby lowering disease incidence and enhancing welfare outcomes.

Another promising frontier is the incorporation of novel feed resources, such as insect meal, microalgae and single-cell proteins. For instance, black soldier fly larvae (BSFL) offer high-quality protein, valorize organic waste streams and provide bioactive compounds that may further support immunity and growth. By reducing dependency on soybean and fishmeal, such innovations also strengthen the sustainability of feed supply chains. Additionally, advances in nutrigenomics and biomarker-driven nutrition allow diets to be tailored to genetic and physiological profiles, enabling early prevention of metabolic disorders and optimizing reproductive and productive performance.

Collectively, these nutritional innovations offer a unique opportunity to realign livestock production with one health goals, addressing animal health, welfare and environmental concerns simultaneously. Their potential lies not only in boosting productivity but also in fostering resilient, sustainable and welfare-oriented production systems capable of meeting future global demands. As such, nutrition is evolving from a supportive input to a transformative lever for the future of livestock farming.

Traditional nutrition focused mainly on meeting averaged nutrient requirements to maximize growth or milk yield. Today, three forces demand a change:

- 1. Animal health and antimicrobial resistance (AMR):** Nutrition can modulate gut health and immunity, reducing reliance on antibiotics.
- 2. Economic and resource efficiency:** Feed is ~60–70% of variable costs in many systems; precision approaches promise reduced waste and input costs.
- 3. Sustainability and welfare pressures:** Consumers and regulators expect lower emissions, circularity and demonstrable welfare outcomes that nutrition can influence (e.g., reducing metabolic disorders, improving resilience).

Above these drivers make nutritional innovation an interdisciplinary switch.

Innovative nutritional approaches

Precision nutrition and precision feeding

Tailoring feed composition and intake of individual animals for varying physiological states in real time using sensors for weight and feed consumption measurements. Precision feeding reduces nutrient oversupply (lower N and P excretion), improves feed conversion and often increases individual performance while supporting health. Studies and industry pilots report feed cost reductions and lower nutrient waste; precision approaches are particularly promising in pigs and poultry where individual feed control is easier.

Application of probiotics, prebiotics, synbiotics and phytogenics

Using feed ingredients or feed additives that modulate gut microbiota and mucosal immunity examples include selected probiotics, prebiotic fibres, organic acids, phytogenic compounds (essential oils, plant extracts) and their combinations. Gut health underpins nutrient digestion, pathogen resistance and systemic immunity. Additives that promote beneficial microbiota can reduce enteric disease, improve nutrient utilization and reduce the need for therapeutic antibiotics.

Potential impacts:

Lower incidence of enteric infections and diarrhea especially in young animals,
Improved feed efficiency and growth rates,
Potential improvements in product quality (meat and milk),

Novel protein and ingredient sources

Replacing or supplementing conventional protein sources such as soybean meal and fishmeal with insect meals (e.g., BSFL larvae), microalgae, yeast and bacterial single-cell proteins and other up-cycled by-products. These alternatives can reduce dependency on land-intensive crops, valorize organic waste streams and provide functional nutrients (lipids, antimicrobial peptides) that influence immunity and gut health. The BSFL are the most advanced pilot and commercial operations show they can replace a portion of soybean / fishmeal in poultry, swine and aquafeeds without compromising performance.

Potential impacts:

Supply-chain resilience and circularity (waste → feed),
Potentially improved fatty-acid profiles or bioactive components that support welfare,
Reduced pressure on wild fisheries and soybean land use,

Application of enzymes, organic acids and targeted nutrient matrices

Strategic use of exogenous enzymes, organic acids in the ration of livestock and poultry and diets formulated increase nutrient availability from plant ingredients, lowering feed costs and reducing anti-nutritional effects. Organic acids can lower gut pH, inhibiting pathogens and improving digestibility in young animals. These tools enhance feed efficiency and health, especially in low-input or cereal-heavy diets.

Potential impacts: Improved nutrient absorption, more predictable growth, reduced pathogen load in the gut, lower emissions per unit product.

Nutrigenomics, biomarkers and personalised herd nutrition

Using genomic, transcriptomic and metabolomic markers plus blood/milk biomarkers to design diets tuned to genetics, life-stage and physiological state. Genetic variation affects nutrient requirements and disease risk. Coupling genetic and biomarker data with diet formulation enables tailored nutrition for resilient, productive animals and can identify animals that would benefit from specific supplements (e.g., precision micronutrition to prevent ketosis in dairy). Early studies demonstrate useful biomarker panels for metabolic status and immune competence; the field is moving from proof-of-concept to on-farm decision support.

Potential impacts: Lower disease incidence (metabolic and infectious), optimized reproduction, targeted use of costly supplements only where needed.

Delivery systems, slow release and functional feeds

Encapsulation, micro-encapsulation, and feed matrices that protect bioactive compounds through the upper gut for targeted intestinal release or that provide time-release nutrients to smooth metabolic load. Many phytogenics, probiotics or vitamins are inactivated in feed or stomach; better delivery increases efficacy and reduces dose/cost. Functional feeds can also be formulated to reduce behaviours linked to poor welfare (e.g., satiety formulations to

reduce aggressive feeding behaviour in group housed pigs). These technologies are maturing alongside feed-manufacturing advances.

Integration with precision livestock farming (PLF) and digital twins

Combining nutrition data with sensor data (activity, rumination, weight and temperature), real-time analytics and digital twin models to simulate and optimize feeding strategies. Nutrition decisions become dynamic: daily rations adjust by cohort health status, weather, milk output or behaviour signals. Digital twins enable scenarios and predictive interventions.

Evidence of impacts on health, productivity and welfare

The evidence base is growing rapidly. Meta-analyses and industry trials report improved feed conversion and growth when precision feeding systems or validated feed additives are used; average responses vary by species and baseline nutrition, but improvements are often in the range of a few percent economically meaningful at scale. Microbiome-modulating additives (phytogenics, probiotics) reduce incidence and severity of enteric disease in young animals and modulate immune markers; precision feeding reduces metabolic disorders by matching supply to need.

Welfare indicators: Nutrition affects behavior (hunger, stereotypies), physiological stress (cortisol proxies) and physical health (lameness, mastitis risk through metabolic status). Feeding systems that reduce competition, provide appropriate roughage (for ruminants) and smooth nutrient supply improve welfare metrics. Integrated PLF can detect welfare compromises earlier via feeding patterns.

Sustainability and circular economy co-benefits

Many nutritional innovations also reduce environmental footprint:

Precision feeding and improved digestibility reduce enteric methane and nutrient excretion intensity. Insect meals and upcycled by-products convert organic wastes to animal protein, reducing reliance on soybean and fishmeal and improving nutrient recycling. Commercial insect farms are scaling but face cost and regulatory constraints.

These co-benefits make nutritional innovation attractive for climate-smart and regenerative livestock systems but the scale of environmental gains depends on system boundaries and feed production methods.

Barriers, risks and limitations

Advanced feeds and precision systems require capital and reliable supply chains; many smallholders lack access. Cost-benefit is context-specific.

Novel ingredients (insect meal, single-cell proteins) face variable legislation and consumer perception barriers in different markets.

Additives (probiotics, phytogenics) show variable outcomes across diets, breeds and environments; standardization and evidence-based claims are needed.

Precision nutrition depends on interoperable sensors, data standards, and farmer capacity to interpret outputs. Digital divides can worsen inequity.

New feed sources require rigorous monitoring for contaminants, allergens and bioaccumulation; long-term studies are still accumulating.

Practical pathways for adoption (for industry and research)

1. ***Pilot and scale-up with economic trials:*** Use on-farm pilots to quantify local ROI and animal health outcomes before large investments. Precision feeding pilots in pigs/poultry have demonstrated measurable feed and emission reductions.
2. ***Develop evidence packages for feed additives and novel ingredients:*** Randomized controlled trials, meta-analyses and standardized reporting will build confidence for veterinarians and regulators.
3. ***Policy and standards:*** Harmonize regulations for insect and single-cell proteins, and certify welfare-oriented feeding systems to support market access.
4. ***Farmer training and data services:*** Provide user-friendly dashboards, decision support, and extension services to interpret precision feeding outputs and integrate nutrition with health management.
5. ***Cross-disciplinary research:*** Combine animal nutritionists, microbiologists, engineers, data scientists and social scientists to design solutions that are technically robust and socio-economically viable.

High-priority research and innovation needs

Contextual efficacy studies: Multi-site trials of probiotics, phytochemicals and insect meals across climates, breeds and production systems to identify conditions for success.

Biomarker validation: Robust metabolic and immune biomarker panels that inform actionable dietary changes (early detection of ketosis, subclinical infections).

Cost reduction and scale for novel proteins: Improve rearing, processing and logistics for insects and single-cell proteins to match price and consistency of soybean meal and/or fishmeal.

Interoperability and AI models: Standard data formats and validated algorithms for precision feeding and digital twin simulations that generalize across farms.

Welfare-oriented feed formulations: Experimental work linking specific dietary strategies to behaviour, stress physiology and long-term welfare outcomes.

Conclusion

Innovative nutritional approaches are redefining the role of feed in livestock systems, shifting it from a basic input to a strategic driver of health, productivity and welfare. Precision feeding, microbiome modulation, alternative protein sources and nutrigenomic interventions collectively demonstrate the potential to reduce disease incidence, enhance feed efficiency and improve animal resilience while addressing sustainability concerns. These innovations not only lower reliance on antibiotics but also support welfare by preventing metabolic stress, improving gut health and aligning diets with animals' physiological needs. Furthermore, the integration of circular feed resources such as insect meals strengthens food system sustainability. While challenges remain in cost, scalability and regulatory acceptance, the trajectory is clear: nutrition will be central to creating resilient, welfare-oriented and environmentally responsible livestock production. Harnessing these approaches effectively requires collaborative research, supportive policies and farmer-focused adoption strategies to ensure their full impact.



Maize Trait Selection for Improved Bioethanol Recovery: A Breeding Perspective



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Maize, popularly called as corn, holds immense significance globally, serving various purposes ranging from culinary to industrial. It holds immense potential in providing food, feed, fodder and fuel. Apart from food and feed it is utilized in various industrial processes. It serves as a raw material in the production of ethanol, a biofuel used as an alternative to gasoline. Several crops are suitable for bioethanol production, specially crops that contain high levels of fermentable sugars that can be easily converted into ethanol through yeast fermentation like, sugarcane, sugar beet, sweet sorghum, cassava, rice straw, wheat straw and maize etc. Not all sugar crops are used commercially for bioethanol production due to a combination of economic (having low starch yield per hectare, high production costs and competing uses), agronomic (low adaptability and short shelf life), technical, and policy-related factors. Commercial ethanol production often depends on favourable policies also. Many sugar-rich crops are more valuable for food or industrial uses (e.g., fruits for fresh markets, molasses for animal feed), making them less economically attractive for fuel production. Only a few sugar crops like sugarcane, sugar beet, sweet sorghum and maize are commercially viable for bioethanol production due to their high sugar content, yield efficiency, adaptability, and existing infrastructure. Among them maize holds importance as a fuel primarily through its conversion into ethanol as it has high starch yield (2.31 tonnes/hectare). Sugarcane gives the highest raw starch equivalent per hectare because of its massive fresh biomass, but in practice this starch is mostly in the form of sucrose, not stored granules like in cereals. It's often converted to sugar or ethanol rather than extracted as starch. Although rice has a slightly higher starch yield per hectare than maize under average Indian yields, but maize hybrids with high productivity (>6 t/ha grain) can surpass rice. Therefore, over sugarcane and rice, maize is preferred for industrial starch because extraction is easier and purer compared to rice, and it produces a co-product stream (germ for oil, gluten feed) also. Other sugar crops face practical constraints that limit their use at scale.

Crop	Average grain/cane yield (t/ha)	Average starch content (%)	Average starch yield (t/ha)	Uses
Maize	3.3	~70%	2.310 tonnes	High starch, commonly used earlier for feed, less for ethanol, food, industry
Rice	4.1	~78%	3.198 tonnes	High starch, less efficient per ha than maize
Sugarcane	81	~12% (in juice, by fresh weight)	9.720 tonnes	Low starch; mainly grown for sugar, not starch

Sources: Directorate of Economics & Statistics, GOI; FAO; literature on carbohydrate composition)

In many countries, including India, mandatory production, targets, subsidies, policy support and research focus primarily on major crops like maize and sugarcane, not alternative sugar crops. Lately, maize has started being used to make ethanol for mixing with petrol. Distilleries usually run on sugarcane molasses and juice from November to April, when sugarcane is available. During the rest of the year (May to October), they use grains instead. Earlier, they mainly used surplus rice from the Food Corporation of India. But since the government stopped providing rice due to low stock and food security concerns, water depletion concerns and crop diversification, distilleries have turned to maize. This is primarily due to the main concern of depleting water table in India especially Punjab and Haryana (majorly depends on rice-wheat cropping system). Currently, ethanol is a biofuel derived from maize starch or sugar. The significance of maize is increasing and its popularity among

the farming community is also increasing. It has been considered as a crucial candidate crop for bioethanol production and crop diversification for sustainable future due to adaptability to varying environmental conditions and high yield potential. Maize serves as a key raw material for ethanol production, with the high starch content in its kernels being transformed into ethanol through the fermentation process. The process of converting maize to ethanol (*via* fermentation of starch to sugars) is mature and commercially viable. Moreover, its adaptability to grow in diverse agroecological zones makes it a versatile crop, while its role in bioethanol production supports rural economies, generates income for farmers and creates jobs across the supply chain. It can be regrown annually, making it a more sustainable alternative to ethanol production.

In the past producing bioethanol from maize is a well-established method of generating renewable fuel, especially in countries like the United States and Brazil. Now in India also, The Government of India has increasingly turned its attention to maize as a feedstock for bioethanol production to diversify raw material sources and reduce dependence on sugarcane. Under the National Policy on Biofuels, maize is now promoted as a key grain for ethanol blending with petrol, especially during the off-season when sugarcane availability is low. This shift not only supports the 20% ethanol blending target by 2025 but also provides farmers with new market opportunities, encourages crop diversification, and helps in sustainable water use compared to sugarcane and rice. To meet the growing demand for bioethanol under India's ambitious blending targets, there is a pressing need to develop maize hybrids with ideal breeding traits for high grain yield and starch-rich kernels. Such traits include high biomass production with efficient partitioning towards the grain, enhanced starch accumulation with optimum amylose-amylopectin ratio, drought and heat tolerance for stable yields under climate variability, and resistance to major pests and diseases to reduce yield losses. Breeding efforts that integrate these traits will ensure consistent grain availability, maximize starch output per hectare, and support the continuous, large-scale feedstock supply required for bioethanol production without compromising food and feed security. Understanding the traits that contribute to high bioethanol recovery in maize is critical for developing cultivars optimized for biofuel production. Therefore, when breeding maize for bioethanol production, the ideal traits to focus on must be categorized to ensure high yield and efficient bioethanol conversion.

Breeding traits: Collectively, the traits, kernel type, size, endosperm, grain-filling duration, genetics, and moisture helps to determine the overall starch yield and quality of maize grains, which is important for food and bioethanol production.

Maize grain characteristics play an important role in determining starch content, which is crucial for both food and industrial uses like bioethanol production. Kernel type influences starch levels, with dent and waxy maize generally containing more starch than flint or popcorn types; waxy maize is especially rich in amylopectin, which is easier to convert into fermentable sugars. Kernel size and weight also matter, as larger and heavier kernels tend to store more starch, and a high 1000-kernel weight is a good indicator of starch potential. The endosperm, being the main storage tissue for starch, affects total starch content. Therefore, grains with a higher proportion of hard endosperm (vitreous) usually have more starch. A longer grain-filling period or long duration hybrids helps maize kernels store more endosperm and more starch. During this time, the plant moves sugars and nutrients into the developing grains. The longer this period lasts, the more sugars are converted into starch, producing larger and heavier kernels with higher starch content. The genetics of the maize plant play an important role in how much starch its grains can store. High-starch hybrids are maize varieties that have been specifically bred to produce more starch in their kernels. Choosing these hybrids ensures higher starch yield per hectare. Genes controlling starch biosynthesis are the specific genes in the plant that regulate how starch is made and stored in the grain. For example, ADP-glucose pyrophosphorylase (AGPase) is an enzyme controlled by a gene that is crucial for starting starch synthesis in the kernel. If this enzyme is more active or efficient, the plant can produce and store more starch. Finally, moisture content at harvest affects measurable starch, with drier grains (around 14% moisture) showing higher starch per unit weight. Collectively, these traits determine the starch yield and quality of maize grains.

Grain Characteristic	Effect on Starch Content	Explanation
Kernel Type	Higher in dent and waxy maize	Dent and waxy maize generally have more starch than flint or popcorn; waxy maize is rich in amylopectin, which is easier to convert into fermentable sugars.
Kernel Size and Weight	Larger, heavier kernels store more starch	High 1000-kernel weight indicates higher starch potential.
Endosperm Composition	Hard (vitreous) endosperm leads to more starch	Endosperm is the main storage tissue for starch; higher proportion of hard endosperm increases total starch content.
Grain-Filling Duration	Longer duration leads to more starch accumulation	Longer grain-filling in long duration hybrids allows more sugars and nutrients to move into kernels, converting them into starch and producing larger, heavier grains.
Genetic Factors	High-starch hybrids and key genes increase starch	Hybrids bred for high starch and genes like ADP-glucose pyrophosphorylase (AGPase) enhance starch biosynthesis and accumulation.
Moisture Content at Harvest	Drier grains (~14% moisture) → higher measurable starch	Lower water content increases starch per unit weight of grain.

Agronomic traits: Agronomic traits are key to the field performance and productivity of maize for bioethanol production. High grain yield is essential, as it determines the amount of starch available for fermentation and the total ethanol output. Achieving this requires efficient photosynthesis, good use of resources, and a strong balance between growth and grain filling. A sturdy plant structure with strong stalks, the right height, and well-arranged leaves supports biomass production and prevents lodging, which is important for mechanical harvesting and reducing losses. Resistance to major pests and diseases like borers, rusts, and blights helps keep yields stable and reduces chemical use. Together, these traits ensure a steady supply of good-quality maize, making large-scale bioethanol production more reliable and economically viable.

Biochemical traits: Biochemical traits play a big role in how efficiently maize can be used to make bioethanol. The most important factor is how much starch the grain contains and what type of starch it is. More extractable starch means more fermentable sugars, especially glucose, after it's broken down by enzyme, this directly increases ethanol yield. Starch is made up of amylose and amylopectin. Amylopectin's branched structure makes it easier for enzymes to break it down into sugars. That's why maize with more amylopectin (like waxy maize) is preferred for ethanol production as it allows faster and more complete fermentation. Besides starch, other parts of the plant matter too, especially for second-generation ethanol (made from stover, cobs, and other residues). Components like cellulose and hemicellulose can be converted into sugars, but lignin is a tough part of the cell wall that makes this process harder. Less lignin, or lignin with a better structure, improves how easily biomass can be digested by enzymes. However, complete reduction of lignin is not desirable as lignin is also an important for plant strength and stress resistance, so the goal is to adjust its amount and composition without harming plant health. For example, changing the ratio of syringyl to guaiacyl lignin can make it easier to break down during processing. To achieve these traits, breeders can use traditional breeding, marker-assisted selection, and even genetic engineering to target genes involved in lignin production. Modern genomic tools also help identify the genes and regions of the genome linked to better biomass digestibility. By improving starch quantity and structure, and optimizing lignin and cell wall properties, maize can be made much more efficient for both first and second-generation bioethanol production that helps to ensure high yields and sustainable fuel production. For second-generation bioethanol production, breeding maize with less lignin, a better lignin structure, and more cellulose compared to lignin is important to make the plant material easier to break down into fuel. If maize plants have less lignin, a better lignin structure, and more cellulose, their cell walls are easier to break down. This means less energy and fewer chemicals are needed before making ethanol, which makes the process cheaper and more eco-friendly. Breeding maize with these traits is important for producing second-generation bioethanol efficiently.

Physiological traits: Physiological traits are very important for keeping maize productive, especially under challenging environmental conditions for large-scale bioethanol production. One key trait is photosynthetic

efficiency, which helps the plant make more sugars from sunlight. Better photosynthesis, supported by traits like higher chlorophyll content, efficient stomata, and good light use, increases both grain yield and stover biomass, which are important for first and second-generation ethanol. High photosynthesis also helps the plant use water and nutrients more efficiently. Therefore, the plant architecture with erect and semierect leaves are preferred for better photosynthetic activity with narrow leaf angle. Another important trait is nutrient use efficiency, especially for nitrogen and phosphorus. Plants that use nutrients efficiently need less fertilizer, reduce costs, and cause less environmental damage. These traits are very useful in areas with limited resources, helping maintain soil health and long-term maize production. Stress tolerance is also essential. Drought-tolerant maize can survive with less water by having deeper roots, storing water in cells, and using it efficiently, keeping photosynthesis and growth steady. Heat-tolerant varieties maintain stable yields even during high temperatures by protecting enzymes and reproductive processes. Together, these physiological traits ensure consistent grain and biomass production, which is critical for reliable bioethanol feedstock.

Integrating these physiological traits into breeding programs enhances the resilience and sustainability of maize production systems tailored for bioethanol. This ensures consistent raw material supply regardless of environmental fluctuations, thereby supporting the economic and environmental goals of renewable biofuel development. By integrating all breeding, agronomic, physiological, biochemical traits through targeted breeding strategies, it is possible to develop maize varieties that not only perform well agronomically but also provide high-quality feedstock optimized for bioethanol production processes.



Vertical Farming: The Future Frontier Revolutionising Sustainable Vegetable Production



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Introduction:

Soil fertility has been negatively impacted by natural disasters, uncontrolled pesticide and chemical use, global warming and rapid urbanization. Furthermore, each person now has less land available to them, and soil fertility and production have drastically dropped (Lambin, 2012). The watershed's water resources are in danger due to a number of factors, including excessive irrigation, unregulated water contamination and uncontrolled groundwater levels (Bhanja *et al.*, 2018). By 2050, there will likely be more than 9.7 billion people on the planet, requiring a 50% increase in global food production. These issues pose a severe challenge to traditional soil-based agricultural production methods, which makes the current situation of food production extremely difficult. Modern, more productive and ecologically friendly farming technology must be used in addition to soil-based farming methods. Modern agricultural problems like diminishing soil fertility, depleted nutrient stocks, limited access to irrigation water and the effects of climate change may be resolved by soilless production techniques like hydroponics, aquaponics and vertical farming (Albadwawiet *et al.*, 2022). These developments can safeguard water resources, increase space and water conservation and allow for the production of food in urban locations (Sengupta and Banerjee, 2012). They are beneficial since they cut water use by 95% in India, where irrigation uses 84% of available water resources (Cicekli and Barlas, 2014). Additionally, the process is streamlined because 2400 acres of conventional agriculture may yield the same amount of production as a 30-story vertical farm (Eaves and Eaves, 2018). Since vertical farming techniques can also address environmental problems and global food shortages, they may provide a viable solution for urban communities that are at risk, as well as an alternative to the current paucity of arable land and water supplies.

What is Vertical Farming?

Vertical farming is a cutting-edge kind of farming that efficiently uses limited space by growing crops in stacked layers or on sloping surfaces. It combines cutting-edge technology like hydroponics and aeroponics to grow plants without soil in a regulated setting. In order to ensure year-round agricultural production and reduce water and pesticide use, plant roots are suspended in nutrient-enriched water or air. This approach provides a sustainable way to satisfy the growing need for food worldwide and is especially well-suited for rooftops, warehouses, urban areas and even uncultivable ground (Al-Chalabi, 2015). Numerous growing systems that differ in scale, users, technologies, locations and goals are included in vertical farming. It works particularly effectively for growing green vegetables and other horticultural crops. The basic concept of "vertical farming" is growing plants on multiple levels to boost productivity in a limited space. By carefully controlling every aspect of plant growth, including temperature, light, CO₂ concentration, humidity, water and nutrients, a "vertical farm" is a method of cultivating plants indoors that is meticulously regulated or an intricately designed indoor plant system that can yield fresh and high-quality produce year-round.



Fig 1: Vertical farming systems

Table 1: Comparison of Traditional Agriculture and Vertical Farming

Characteristic	Traditional Agriculture	Vertical Farming
Land Use	Extensive	Intensive
Water Consumption	High	Low
Pesticide Use	Common	Minimal
Crop Yield	Moderate	High
Labor Requirement	High	Moderate
Energy Efficiency	Low	High
Weather Dependency	High	Low
Transportation Costs	High	Low
Carbon Footprint	High	Low
Urban Accessibility	Low	High

Source: Panotra *et al.*, (2024)

Vertical Farming: A Brief History:

Vertical farming originated in Babylonia, as demonstrated by the Hanging Gardens, which date back to 600 BC and were regarded by Greek civilization as one of the Seven Wonders of the Ancient World. The term "vertical farming" was coined in 1915 by Gilbert Ellis Bailey, who wrote the book "Vertical Farming." In the 1930s, William Gericke published "The Complete Guide to Soilless Gardening", which established the principles of soilless gardening. This book gained popularity in the history of vertical farming. Professor Dickson Despommier first proposed the idea of vertical farming in 1999 with the goal of growing food inside cities. His plan was to cultivate food near cities in order to reduce the time and distance required for transportation. This strategy aimed to establish food production in urban settings in order to deliver fresher goods faster and at a lower cost. In response to the challenges posed by traditional agriculture, such as the scarcity of water, the limited amount of arable land and the ecological effects of these operations, the concept of vertical farming has attracted a lot of interest recently. The first commercial vertical farm, Sky Greens, was established in Singapore in 2012, proving that it was feasible to produce vegetables in stacked, controlled units. This gave vertical farming systems a boost on a global scale. Large-scale urban vertical farms that specialized in high-value crops, leafy greens and herbs were established in nations including the US, South Korea and Japan after this invention.

Technical Implementations in Vertical Farming:

(1) **Hydroponics:** The predominant growth technique used in vertical farming, hydroponics, involves growing plants without the use of soil in nutrient-enriched solutions. To maintain the proper chemical balance, plant roots are submerged in a nutritional solution that is continuously observed and recirculated. This method allows for precise control over the nutrients supplied to the plant, ensuring optimal growth and development.

Table2: Hydroponic Systems and Their Characteristics

Hydroponic System	Characteristics
Wick System	The Wick system is a low-cost hydroponic method that absorbs nutrients via capillary action through roots and inert material. It's useful for teaching hydroponics culture in areas with limited power access and educational institutions. However, it's not suitable for sustainable crop production, especially for small farmers.
Deep Water Culture (DWC)	The Deep-Water Culture technique in hydroponics involves suspending plant roots in nutrient-rich water, using an air stone for air supply. Plants are grown in net pots, with oxygen, nutrients, pH, and salinity monitored to prevent mould and algal formation.
Nutrient Film Technique (NFT)	The nutrient film technique (NFT) exposes plant roots to nutrient-rich water through horizontal pipes. It's more complicated and expensive than media bed culture but offers a low evaporation rate. Channel slope, length, and flow rate must be calculated for optimal water flow, oxygen, and nutrients.
Drip Irrigation System	The drip hydroponic system involves placing a water tank below the growing tray, where tubes carry water to plants, thereby conserving runoff water and ensuring optimal water distribution.
Ebb and Flow (Flood and Drain)	The method involves submerging plants in a nutritional solution in a repetitive manner and then draining the solution back into a reservoir. The repeated repetition of this cycle enables the supply of nutrients and oxygen to the roots.

Source: Khatri *et al.*, (2024)

(2) **Aeroponics:** When NASA was looking for efficient ways to grow plants in space in the 1990s, it coined the word "aeroponics," which refers to growing plants in a mist/air environment without soil and with little water. Aeroponic systems are becoming more and more widespread in vertical vegetable production, albeit still being rare. With up to 90% less water usage than even the most successful hydroponic systems and no need for replacement growing materials, the aeroponic system is by far the most efficient and environmentally friendly plant-growing technology for vertical farms. Additionally, it has been shown that plants grown in aeroponic systems consume more vitamins and nutrients, which may make them more nutrient-dense and healthier. Aeroponic systems are beginning to receive a lot of interest, despite not being utilised in vertical farming very frequently yet.

(3) **Aquaponics:** Building on the ideas of hydroponics, aquaponic systems combine fish and plants in a single space. This arrangement uses the nutrient-rich faeces produced by fish kept in indoor ponds to feed plants inside vertical farms. The effluents are then returned to the fishpond after being clarified by these facilities. Aquaponics is used in smaller-scale vertical farming systems, although commercial vertical farms usually concentrate on growing a small number of quick-growing food crops without using aquaponics.

GROWING SYSTEMS



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Fig 2: Different technical implementations of vertical farming

Table 3: List of crops grown under vertical farming

Crop Category	Examples
Leafy Greens	Lettuce, Spinach, Kale, Arugula, Swiss Chard
Herbs	Basil, Mint, Cilantro, Parsley, Rosemary
Microgreens	Radish, Broccoli, Sunflower, Pea Shoots, Wheatgrass
Fruiting Crops	Tomatoes, Peppers, Cucumbers, Strawberries, brinjal
Root Crops	Carrots, Radishes, Beets, Turnips, Potatoes

Source: Panotraet *et al.*, (2024)

Table 4: Vegetables and Their Vertical Farming Suitability

Category	Vegetable Examples	Vertical Farming Suitability
Leafy Greens	Lettuce (Romaine, Butterhead, Iceberg)	High
	Spinach	High
	Kale	High
	Arugula	High
	Swiss Chard	High
Herbs	Basil	High
	Parsley	High
	Mint	High
	Cilantro	High
	Dill	High
Fruiting Vegetables	Tomatoes (Cherry, Beefsteak)	Moderate to High
	Bell Peppers	Moderate
	Cucumbers	Moderate
	Eggplant	Moderate
Root Vegetables	Radishes	Moderate
	Carrots	Low
	Beets	Low
Microgreens	Broccoli, Mustard, Radish Shoots	High

(Source: Verma *et al.*, 2024)

(4) **Hi-tech Vertical Farming Methods:**

- (a) **LED illumination:** By providing particular light spectrums required for photosynthesis, advanced LED lighting systems replicate natural sunshine. These energy-efficient lights can be adapted to the particular developmental stages of crops, guaranteeing ideal plant development.
 - (b) **Systems for Climate Control:** These climate control systems regulate airflow, temperature, humidity and carbon dioxide levels. These systems improve production and crop quality by establishing a stable environment that permits year-round cultivation irrespective of external weather conditions.
 - (c) **Automation and IoT:** These days, automation and the Internet of Things (IoT) are essential components of vertical farming. Sensors and actuators allow for real-time monitoring of variables like ambient conditions, light intensity and nutrition levels. Automation will guarantee efficiency in processes while lowering labour expenses and ensuring uniformity.
 - (d) **Energy-Efficient LED Lighting:** LED innovations have become more sophisticated and energy-efficient, even enabling lights that are tailored to the individual requirements of the plants. Now that LEDs can be adjusted to emit particular light wavelengths, photosynthesis can be optimized at various stages of growth. Additionally, they generate the least amount of heat, which lowers the need for cooling. This enables them to approach the plants even closer, maximising the use of available space.
 - (e) **Automated Nutrient Delivery Systems:** Systems that can continually monitor and make modifications in real-time were introduced by advancements in automated nutrient management. These systems make use of sensors that monitor electrical conductivity (EC), pH levels and nutrient concentrations to guarantee waste-free, optimal nutritional availability.
 - (f) **Machine Learning (ML) and Artificial Intelligence (AI):** In fact, predictive farming models for vertical and hydroponic farming now heavily rely on AI and ML. AI uses environmental data to forecast crop yield, spot possible problems with pest threats or nutrient shortages and optimize resource use. For instance, computer vision technology can detect early indicators of plant stress and diseases, allowing for prompt interventions.
 - (g) **Renewable Energy Source Integration:** Integrating renewable energy is lowering these systems' carbon impact. Vertical farming operations are increasingly being powered by wind turbines and solar panels. By guaranteeing energy availability during off-peak hours, battery storage systems increase the systems' sustainability and self-sufficiency.
- (5) **Robotic Vertical Farming Systems:** Because using human labour has both economic and physical constraints, robotic technology is increasingly being used in vertical farming. However, there are challenges in developing effective robotic systems, including the need for human-robot collaboration and the ability to operate in unstructured agricultural environments. Human labour is wasteful and impractical due to the physical limitations of massive constructions and the high density of farming. Autonomous robotic platforms with flexible sensors can be essential to accomplishing these goals in vertical farms. With the help of efficient power management, LED lighting and automated climate control, the iFarm indoor vertical farming system can be customized to allow for year-round, pesticide-free plant growth. Its state-of-the-art technologies include a chatbot for plant image analysis and a neural network that calculates plant mass dynamics. Plant growth and quality can be determined using low-altitude multispectral images, which can help plants use less water and nutrients. Self-governing robots in vertical farms are ideal for this non-intrusive vision technique.

The Rise of Vertical Farming in Vegetable Production:

Using vertically inclined surfaces, like skyscrapers or indoor structures, vertical farming maximizes the use of space and resources, which means that it can cover a significant area for vegetable cultivation in urban settings where land is scarce. These days, vertical farming has been operating as the skyscraper gardens or skyline farms in many cities. Vertical farming plays a crucial role in shaping the urban landscape and contributing to sustainable urban agriculture. With its creative design and proper management, vertical farming can turn unused spaces into productive vegetable gardens. In urban environments, vertical farming can cover a sizable area for growing vegetables, especially in places with limited space. Because of this, vertical farming can be adapted to various urban settings, making it a flexible and scalable method of growing vegetables. In general, the total space used

for vertical vegetable growing might vary substantially depending on the particular layout, patterns and dimensions of the vertical farm.

Necessity of Vertical Farming:

1. **Year-Round Production:** No matter the season, a steady supply of food is guaranteed thanks to vertical farming, which makes it possible to produce food twenty-four hours a day, seven days a week.
2. **Weather Protection:** It shields crops from hazardous and unpredictable weather, removing the dangers of floods, droughts and extremely high or low temperatures.
3. **Water Reuse:** To improve water efficiency and cut down on waste, water used in the farming system is recycled and utilized again indoors.
4. **Space Efficiency:** By stacking crops in several levels or vertically inclined buildings, vertical farming makes better use of available space. This makes it possible to produce more crops per square foot than traditional horizontal farming, which makes it the ideal choice for densely populated metropolitan areas with constrained space.
5. **Decreased Use of Pesticides:** Although pesticides can harm ecosystems and human health, the controlled environment of vertical farms lowers the risk of diseases and pests. The focus on hygienic, controlled conditions in vertical farming helps produce healthier, pesticide-free crops, which is consistent with ecologically friendly agricultural methods.
6. **Decreased Reliance on Fossil Fuels:** Because vertical farms eliminate the need for machinery, transportation and land preparation, all of which normally demand substantial fuel consumption, they considerably lessen reliance on fossil fuels.
7. **Prevention of Crop Loss:** Vertical farming ensures fresher produce by reducing crop loss from spoiling and damage by doing away with lengthy transit and storage periods.
8. **Energy Efficiency:** Vertical farms employ energy-efficient technologies, such as advanced climate control systems and LED lighting, to create the ideal growth conditions. Although there is a one-time energy cost, the environmental impact may be offset by careful management of environmental factors. Additionally, ongoing efforts to incorporate renewable energy sources, such as wind or solar electricity, are intended to further improve vertical farming's energy sustainability.
9. **Water Conservation:** Because of the closed-loop water system and decreased runoff, vertical farming can save up to 95% of the water used in traditional farming.
10. **Reduction of Carbon Emission:** By minimizing the distance, food must travel from the farm to the customer, local vertical farms, particularly those integrated into metropolitan areas, reduce the quantity of carbon emissions from transportation. Thus, vertical farming reduces the effects of climate change and helps create an environmentally friendly food distribution system.
11. **Preservation of Biodiversity:** The effective utilization of available space by vertical farming transforms the growth of agricultural land into natural ecosystems. It helps to preserve biodiversity and safeguards wildlife habitats that sustain ecological balance and conservation initiatives by reducing land clearing.
12. **Crop Stacking & Diversity:** By stacking crops vertically, a large range of crops can be grown concurrently in the same space. By giving customers access to a wider range of nutrients, this diversity improves nutritional variety and tackles issues related to food security.
13. **Job Creation:** As workforce skill sets evolve, vertical farming offers job opportunities in a variety of sectors, including data analysis, research, food science, etc.

Challenges in Vertical Farming:

Challenge	Description
High Initial Costs	Significant upfront investment in infrastructure and technology
Energy Requirements	High energy consumption for lighting, climate control, and automation
Skilled Labor	Need for specialized knowledge and technical expertise
Limited Crop Variety	Not all crops are suitable for vertical farming systems
Public Perception	Scepticism and resistance towards unconventional farming methods
Regulatory Frameworks	Lack of clear regulations and standards for vertical farming
Scalability Concerns	Challenges in expanding and replicating vertical farms on a large scale

Conclusion:

With the anticipated growth in urban populations, vertical farming is intended to greatly enhance food sustainability in urban environments. When compared to conventional rural farming practices, this approach has several advantages in terms of social, environmental and economic factors. By lowering the dependency on soil-based farming, innovations like hydroponics, aeroponics and aquaponics are transforming agricultural methods. In areas with scarce soil and water resources, vertical farming, which enables the year-round production of vegetables in small areas with little labour, is especially beneficial to underserved communities. India anticipates significant expansion in this sector, which calls for the creation of affordable technologies like hydroponics. But maintaining affordability for low-income urban households is still difficult, made worse by problems like food deserts and slums. The availability of food, population number, technological developments, cultural eating customs and access to electricity and water resources are some of the variables that affect the growth of vertical farming.

Although vertical farming has potential, it is both costly and complex. It is necessary to take into account technical factors, including building, site selection, energy efficiency, crop nutrition, growth systems and lighting. More research is needed to enhance its financial and technological aspects, with a focus on raising output and reducing expenses. To fully realize its potential and decide whether to expand it as a sustainable food production method in the future, cooperation between the vertical farming industry and academia is essential.

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Understanding Robotics in Agriculture: Trends in India



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India's agricultural sector is undergoing a transformative shift with the integration of robotics and automation. As the nation grapples with challenges like labor shortages, climate change, and the need for increased productivity, robotics emerges as a beacon of innovation. This article deals into the current trends, applications, and future prospects of robotics in Indian agriculture.

The Rise of Agriculture

India, one of the world's largest agricultural economies, is rapidly embracing robotics to modernize its traditional farming practices. The growing labor shortage in rural areas, rising operational costs, and the need for increased productivity are driving the adoption of agricultural automation. Government initiatives such as Digital India and Make in India have accelerated R&D in smart farming technologies, encouraging the development and deployment of cost-effective farming robots. Indian startups like Niqo Robotics and Tartan Sense are leading this transformation by creating AI-powered robots designed for small and fragmented landholdings. These solutions, ranging from robotic sprayers to autonomous harvesters, are tailored for India's diverse crops and terrains. Additionally, engineering institutions and local innovators are building rugged, affordable machines that can withstand Indian farming conditions. As awareness grows and technology becomes more accessible, agricultural robotics is no longer limited to large farms but is gradually finding its place among small and medium-scale farmers across the country.

Market Growth

The Indian agricultural robots' market is experiencing significant growth. Valued at approximately USD 91.36 million in 2022, it's projected to reach USD 544.35 million by 2030, growing at a CAGR of 23.6% during the forecast period. This surge is attributed to the increasing demand for precision farming and the need to address labor shortages.

Key Applications of Robotics in Indian Agriculture

1. Precision Farming

Precision farming involves the use of technology to monitor and optimize agricultural processes. Robots equipped with sensors and GPS technology enable farmers to apply water, fertilizers, and pesticides more accurately, reducing waste and increasing yields.



2. Automated Harvesting

Robotic harvesters can identify and pick ripe fruits and vegetables, reducing the reliance on manual labor. These machines are particularly useful in large-scale farms where timely harvesting is crucial.



3. Weeding and Pest Control

Autonomous robots can detect and remove weeds or apply pesticides precisely, minimizing chemical usage and environmental impact. Innovations like hybrid drone-rover vehicles are being developed for such applications.



4. Irrigation Management

Systems like Nano Ganesh allow farmers to remotely control irrigation pumps using mobile phones, enhancing water management and reducing the need for physical presence in the fields.



5. Crop Monitoring

Drones and ground-based robots equipped with cameras and sensors provide real-time data on crop health, soil conditions, and pest infestations, enabling proactive decision-making.



Challenges in Adopting Agricultural Robotics

Despite the promising benefits, several challenges hinder the widespread adoption of robotics in Indian agriculture:

- **High Initial Costs:** The investment required for robotic equipment can be prohibitive for small and marginal farmers.
- **Lack of Technical Expertise:** Operating and maintaining advanced machinery requires specialized knowledge, which may not be readily available in rural areas.
- **Infrastructure Limitations:** Inadequate power supply and internet connectivity can affect the functionality of robotic systems.
- **Cultural Resistance:** Traditional farming practices are deeply ingrained, and there may be reluctance to adopt new technologies.

Government Initiatives and Support

Recognizing the potential of robotics in agriculture, the Indian government has launched various initiatives:

- **Subsidies and Financial Assistance:** Programs to provide financial support for purchasing agricultural machinery.
- **Research and Development:** Funding for R&D in agricultural technologies through institutions like the Indian Council of Agricultural Research (ICAR).
- **Skill Development:** Training programs to educate farmers on the use of modern agricultural tools and technologies.

Future Prospects of Agricultural Robotics in India

The future of robotics in agriculture in India is poised for exponential growth, with developments promising to revolutionize the sector.

1. AI and IoT integration:

The next wave will be powered by IoT in agriculture, where robots will be connected to smart sensors and cloud platforms. These systems will allow real-time decision-making, reducing crop loss and maximizing output.

2. Autonomous multi-functional robots:

Future farming robots are expected to handle multiple tasks such as seeding, spraying, and harvesting autonomously. This multifunctionality will make them more cost-effective and attractive for Indian farmers.

3. Customizable and modular designs:

Robots designed specifically for crops like sugarcane, wheat, cotton, and rice are being tested. Modular builds will allow farmers to add or remove functions as per seasonal requirements.

4. Skill development and adoption programs:

With increased emphasis on digital literacy and agricultural automation training, more farmers are expected to embrace robotic tools. These training programs will make operations like calibration, maintenance, and data analysis more farmer-friendly.

5. Drone-robot hybrids and aerial automation:

The future will see a convergence of aerial drones and ground-based farming robots, offering 360-degree automation from surveillance to action. This kind of integrated smart farming setup can boost both sustainability and efficiency.

Conclusion

The incorporation of robotics in agriculture is no longer a futuristic concept—it's happening now in India, one field at a time. From smart farming tools and agricultural automation systems to IoT-powered robotic devices, technology is offering real solutions to persistent agricultural challenges.

Despite barriers like high costs and limited awareness, the combined efforts of government initiatives, startup innovation, and farmer education are closing the gap. As robotic farming becomes more localized and affordable, it has the potential to transform India's agriculture into a tech-driven, high-efficiency ecosystem.

The journey may be gradual, but with continued investment and education, India is well on its way to becoming a global leader in smart, automated farming practices.



The Transformative Impact of Vegetable Seed Production on the Rural Farming Community



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Vegetable seed production, a specialized and knowledge-intensive arm of agriculture, has emerged as a powerful catalyst for socio-economic development in rural areas. Moving beyond subsistence farming, it offers a high-value alternative that significantly influences income, employment, gender empowerment, skill development, and overall quality of life. This article delves into the multifaceted impact of this enterprise on the rural farming community, supported by empirical evidence and case studies.

For generations, rural farming communities have primarily focused on producing food grains and vegetables for consumption and local markets, often trapped in a cycle of low returns and high risk. The advent of organized vegetable seed production, particularly through contract farming models with agribusiness firms, has redefined this paradigm. It transforms farmers from producers of commodities into creators of valuable genetic material, fundamentally altering their economic and social trajectory.

Economic Impacts: A Direct Pathway to Enhanced Income

The most immediate and significant impact is economic. Seed production is inherently more lucrative than conventional vegetable farming.

Higher Profitability: Seed production operates on a high-value, low-volume model. The income per unit of land is substantially higher. For instance, studies show that the net returns from hybrid vegetable seed production (e.g., tomato, chilli, cabbage) can be 2 to 4 times higher than from growing the same vegetables for the market (Singh *et al.*, 2019). This direct income enhancement increases disposable income, enabling better food security, education for children, and healthcare access.

Risk Mitigation through Contract Farming: A cornerstone of this sector is contract farming. Companies provide farmers with the foundational seed, technical guidance, and inputs on credit, and guarantee to purchase the seed harvest at a pre-agreed price. This model shields farmers from price volatility and market fluctuations, a significant risk in traditional agriculture (Birthal *et al.*, 2005). The assured market reduces uncertainty and encourages investment.

Employment Generation: Seed production is highly labor-intensive, creating substantial on-farm employment opportunities. Activities like transplanting, roguing (removing unwanted plants), hand-pollination (crucial for hybrids), harvesting, and primary processing require meticulous manual labor. This generates gainful employment for landless laborers, women, and youth throughout the production season, leading to a multiplier effect in the local economy (Gautam *et al.*, 2017).

Socio-Cultural Impacts: Empowering Communities

The benefits extend beyond mere economics, fostering profound social change.

Women Empowerment: Vegetable seed production has proven to be a significant avenue for empowering rural women. Many operations, such as pollination and seed sorting, are considered suitable for women and can be done near their homes. This provides them with an independent source of income, enhancing their decision-making power within households and elevating their social status (Ramaswami *et al.*, 2009). Studies from regions like Maharashtra and Karnataka highlight the formation of women-led self-help groups (SHGs) engaged in seed processing, further strengthening their collective agency.

Skill Development and Knowledge Transfer: Engagement with seed companies exposes farmers to advanced agricultural technologies. They receive training in:

Scientific Cultivation: Precise nursery management, irrigation, and nutrient management.

Quality Consciousness: The importance of genetic purity, isolation distances, and post-harvest handling.

Record-Keeping: Maintaining production records as per company requirements. This knowledge transfer builds human capital, making farmers more skilled and efficient, benefits that often spill over to their other agricultural activities.

Improved Social Infrastructure: The clustering of seed production activities in a region can lead to the development of better local infrastructure. Companies may facilitate improved irrigation facilities, better road connectivity for collection, and the establishment of seed processing units, which benefit the entire community.

Challenges and Considerations

Despite its benefits, the model is not without challenges:

Dependence on Companies: Over-reliance on a single company can be risky if the contract is terminated.

Stringent Quality Standards: Seed failure can lead to major financial losses for the farmer, and rejections due to quality issues are a constant source of tension.

Market Fluctuations: While prices are often guaranteed, a glut in the seed market can sometimes lead to pressures on pricing in subsequent seasons.

Conclusion:

Vegetable seed production is far more than an agricultural activity; it is a potent tool for integrated rural development. By providing a stable and high-income source, generating employment, empowering women, and fostering skill development, it creates a sustainable pathway for elevating the socio-economic status of the rural farming community. For policymakers and development agencies, promoting this sector through supportive policies, infrastructure development, and farmer-centric regulations is crucial to harnessing its full potential for creating prosperous and resilient rural communities.

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Anthropogenic Sources of Water Contamination: A Sectoral Analysis



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INTRODUCTION:

Water is an indispensable resource for all forms of life, particularly for human survival, health, and development. It plays a central role not only in sustaining basic physiological needs but also in supporting agriculture, industry, sanitation, and energy production. However, as global populations grow and economies expand, pressure on freshwater resources has intensified significantly. Around 80% of wastewater is released untreated, carrying heavy metals, pathogens, and microplastics, worsening global water insecurity. **Water pollution** refers to the contamination of subsurface groundwater or surface water bodies such as lakes, rivers, streams, estuaries, and oceans by harmful substances or forms of energy. This pollution reaches a level where it disrupts the intended use of the water or interferes with the natural balance and functioning of aquatic ecosystems. **There are three main types of water pollutants: chemical, biological, and physical contaminants.** Each of these plays a significant role in degrading water quality and harming both the environment and public health.

- 1) **Chemical contaminants** are among the most dangerous, as they include a wide range of toxic substances such as **heavy metals** (e.g., mercury, lead, arsenic, and cadmium), which can accumulate in the food chain and pose long-term health risks. Additionally, **pesticides and herbicides** used in agriculture, along with industrial chemicals like **PCBs** (polychlorinated biphenyls) and **PFAS** (so-called "forever chemicals"), often find their way into water bodies through runoff or improper waste disposal.
- 2) **Biological contaminants** refer to the presence of **pathogenic microorganisms** in water, including bacteria such as *Escherichia coli*, viruses like norovirus and hepatitis A, and parasites such as *Giardia* and *Cryptosporidium*. These typically originate from **untreated or inadequately treated sewage**, animal waste, or runoff from farms and urban areas.
- 3) **Physical contaminants** involve materials and energy that alter the physical characteristics of water. These include **plastic waste**, especially **microplastics**, which are small enough to be ingested by aquatic animals, disrupting food webs. **Sediments** from soil erosion, construction sites, and deforestation cloud water and smother aquatic habitats. Moreover, **thermal pollution**, caused by the release of heated water from industrial operations and power plants, can significantly raise water temperatures.

SOURCES OF CONTAMINATION:

1) INDUSTRIALIZATION

Industrial activities are major contributors to water pollution. Sectors such as distilleries, tanneries, textiles, pulp and paper, food processing, iron and steel, and nuclear industries discharge untreated wastewater containing toxic chemicals. Common pollutants include arsenic, cadmium, and chromium, which severely degrade water quality (Chen et al., 2019). Rapid urbanization further increases industrial wastewater volumes (Wu et al., 2020).

2) AGRICULTURAL ACTIVITIES

Agriculture is a major source of water pollution through pesticides, fertilizers, and farm waste, which contaminate surface and groundwater. Runoff carries nitrates, phosphorus, pathogens, and pesticides, degrading freshwater ecosystems. In countries like China and India, untreated wastewater used for irrigation introduces heavy metals and toxins into food supplies, threatening health and safety (Lu et al., 2015). Pesticide-contaminated drinking water increases disease risks; for instance, a 10% rise in pesticide use raised the medical disability index by 1% among elderly populations (Lai, 2017). In India's Musi River basin, wastewater irrigation led to higher morbidity rates.

Pesticides	Nature	Maximum contamination level (MCL), µg/L
Carbofuran	Nematicide	40
Dalapon	Herbicide	200
Dibromochloropropane	Nematocide	0.2
Dinoseb	Insecticide/miticide	7
Dioxin	Herbicide	0.0003
Diquat	Herbicide	20
Endothall	Algicide	100
Ethylene dibromide	Insecticide	0.05
Glyphosate	herbicide	700
Methoxychlor	Insecticide	40
Oxamyl	Insecticide	200
Pentachlorophenol	Fungicide	1
Picloram	Herbicide	500
Simazine	Herbicide	4
Toxaphene	Insecticide	3

Fig 1: List of harmful pesticides (Journal of International Cooperation and Development. (2023). Vol. 6(2), July 2023).

3. NATURAL FACTORS CONTRIBUTION

Natural environmental processes can also lead to water pollution. For example, the Chinese Loess Plateau contains naturally high concentrations of trace elements in its water, resulting from geological weathering and mineral composition. This has led to elevated levels of sodium and salinity, negatively affecting water quality (Xiao et al., 2019).

PATHWAYS OF WATER CONTAMINATION:

1. **Surface Runoff** – Rainfall and irrigation wash sediments, fertilizers, pesticides, heavy metals, oil, and microplastics into rivers and lakes, causing eutrophication and hypoxia. Its diffuse nature makes regulation difficult.
2. **Subsurface Leaching** – Pollutants from farms, landfills, and septic systems percolate into groundwater. Excess nitrates cause health risks like infant methemoglobinemia, while heavy metals and solvents persist for decades.
3. **Direct Wastewater Discharge** – Industries and cities release untreated or partially treated effluents (toxic metals, pathogens, pharmaceuticals) into water bodies. Globally, ~80% of wastewater is untreated, with higher rates in LDCs (UNESCO, 2021).
4. **Atmospheric Deposition** – Pollutants such as SO₂, NO_x, and mercury deposit via rain or fallout. Acid rain alters water chemistry, while mercury bioaccumulates in fish, threatening ecosystems and human health.
5. **Internal Recycling** – Pollutants stored in sediments (e.g., phosphorus, lead, cadmium) can resuspend under anoxic conditions or disturbance, fueling algal blooms and extending pollution impacts.

EFFECTS OF WATER CONTAMINATION:

Water contamination has far-reaching consequences that affect human health, the environment, the economy, and the overall availability of clean water resources.

Human Health Impacts of Water Pollution:

Contaminated water is a major cause of diseases like cholera, typhoid, hepatitis A, and dysentery, especially in regions lacking safe water and sanitation.

Effects on Environment:

Water pollution disrupts aquatic ecosystems by reducing dissolved oxygen, as microbes decompose sewage and organic waste. Oxygen depletion leads to fish kills and biodiversity loss. Excess nutrients (nitrogen, phosphorus) cause algal blooms, which worsen oxygen depletion and accelerate lake ageing. Toxic pollutants like mercury and DDT bioaccumulate and biomagnify through the food chain, harming higher organisms. For example, DDT weakens bird eggshells, causing population declines. These effects demonstrate the long-term ecological consequences of water contamination.

Effects on Aquatic Ecosystem

Polluted water reduces Dissolved Oxygen (DO) content, thereby, eliminates sensitive organisms like plankton, molluscs and fish etc. However, a few tolerant species like **Tubifex (annelid worm)** and some insect larvae may survive in highly polluted water with low DO content. Such species are recognized as **indicator species** for

polluted water. **Biocides, polychlorinated biphenyls (PCBs) and heavy metals** directly eliminate sensitive aquatic organisms. Hot waters discharged from industries, when added to water bodies, lowers its DO content.

Chemicals	Health Impacts
Mercury	Minamata Disease—Mercury is converted into Methyl Mercury by bacterial action, which causes numbness of limbs, lips, and tongue, deafness, blurring of vision, and mental derangement.
Cadmium	Itai-itai disease (ouch-ouch disease) – a painful disease of bones and joints. Cancer of the liver and lung
Nitrate	Methaemoglobinemia or Blue-baby Syndrome – Nitrate reacts with haemoglobin and forms non-functional methaemoglobin that impairs Oxygen transport.
Fluoride	Skeletal fluorosis – hardened bones and stiff and painful joints. Teeth deformity
Arsenic	Black-Foot Disease Diarrhoea Peripheral Neuritis Hyperkeratosis Lung and skin cancers
Lead	Symptoms of Lead exposure: persistent fatigue, irritability, loss of appetite, constipation, insomnia. Effects in Children: damage to brain and nervous system, behavioural problems, anaemia, liver and kidney damage, hearing loss, dev delays. Effects in Adults: poor muscle coordination, nerve damage, high BP, hearing and vision impairment, reproductive problems, and low fetal development.

Fig 2 – Effects on Human health

Eutrophication

Eutrophication is the nutrient enrichment of lakes and water bodies, mainly with nitrogen and phosphorus. A major outcome is algal blooms, often red or brown tides, caused by rapid phytoplankton growth. During the day, algae release oxygen, but at night their respiration and subsequent decay deplete dissolved oxygen, causing hypoxia and fish kills. Oxygen shortage also favors harmful anaerobic bacteria (e.g., Clostridium botulinum), which produce deadly toxins.

Effect in Soil Environment:

Polluted water degrades soil quality by causing nutrient imbalances, excessive nitrates and phosphates, or toxic heavy metal buildup. This reduces crop productivity and can increase soil salinity, especially in arid regions, making land unfit for cultivation. Vegetation loss weakens soil structure, promoting erosion and stripping nutrient-rich topsoil. Heavy metals from industry and mining, along with persistent pesticides and herbicides, alter soil composition and harm beneficial microbes essential for nutrient cycling. As a result, soil fertility declines, agricultural yields drop, and ecosystem stability is undermined.

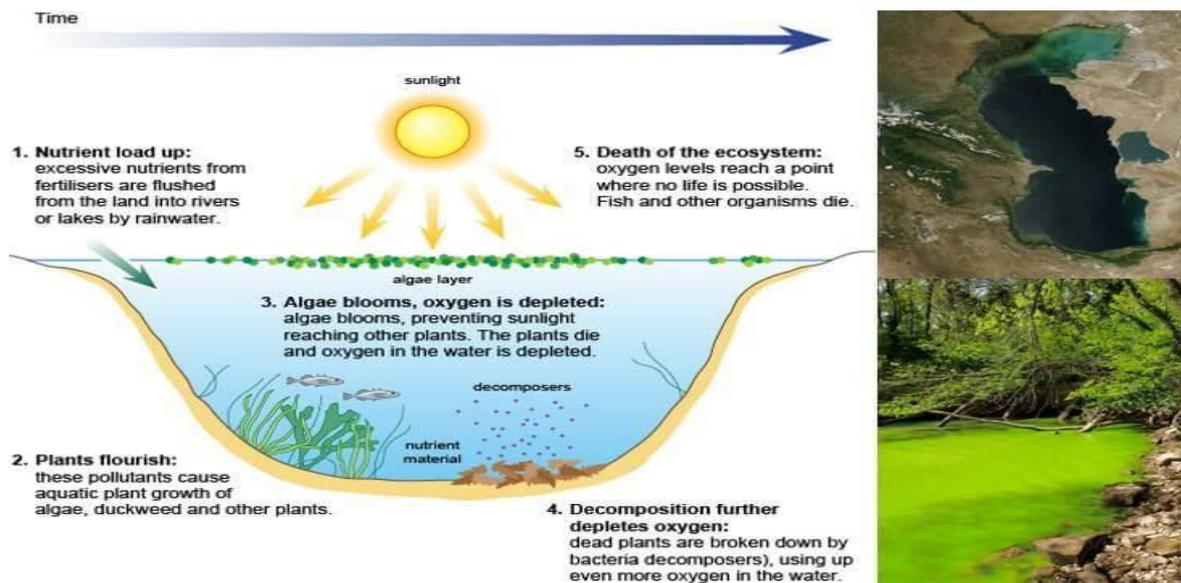


Fig 3 – Eutrophication (Water Pollution: Causes & Effects, Eutrophication, Algal Blooms. (2025, January 8). *General Studies III – Environment*. <https://www.insightsonindia.com>)

Relief Measures:

Water pollution harms ecosystems, health, agriculture, and biodiversity, requiring immediate, short-term, and long-term responses.

- Water Treatment: Sedimentation, filtration, activated sludge, and oxidation remove toxins and pathogens.
- Ecological Restoration: Reintroducing native plants, restocking fish, aeration, and bioremediation help revive ecosystems.
- Public Health Relief: Emergency clean water supply, purification units/tablets, medical camps, and disease screening reduce health risks.
- Awareness & Education: Campaigns on safe water use, waste disposal, and reduced chemical farming promote prevention.
- Economic & Social Support: Compensation, alternative jobs, and subsidies aid affected farmers and fishermen.
- Regulation & Enforcement: Penalties for illegal discharges, monitoring stations, and mandatory pollution controls in industries.
- Long-term Resilience: Green infrastructure (wetlands, buffer zones), oil spill/chemical leak response teams, protective bunds, and community-led conservation.

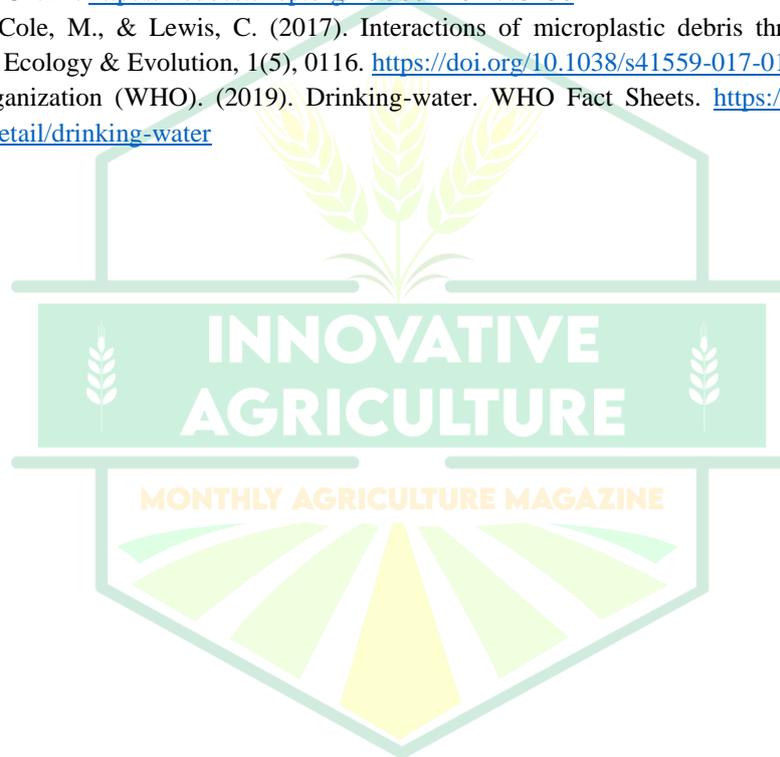
Conclusion:

Water pollution remains one of the most pressing environmental challenges of our time, driven by unchecked industrial discharge, agricultural runoff, and improper waste management. Its consequences are far-reaching, affecting not only aquatic life but also human health, agriculture, and biodiversity. Eutrophication and algal blooms, caused by excess nutrients like nitrogen and phosphorus, serve as visible indicators of ecological imbalance, leading to oxygen depletion and the collapse of aquatic ecosystems. Addressing water pollution requires a multi-pronged approach involving stricter regulations, technological intervention, community awareness, and sustainable practices in agriculture and industry. Only through collective and sustained efforts can we restore the health of our water bodies and ensure safe, clean water for future generations.

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Nano Fertilizers: The Future of Crop Nutrition



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Abstract

Nanofertilizers are an innovative solution addressing the inefficiencies of traditional fertilizers by enhancing nutrient use efficiency and reducing environmental impact. Engineered at the nanoscale, they enable targeted, controlled nutrient delivery, boosting crop yield and soil health. In India, where soil degradation and water scarcity pose major challenges, nanofertilizers like Nano Urea show promising results. They offer economic and ecological benefits through reduced input use and pollution. Despite regulatory and scalability challenges, their integration with smart farming technologies marks a leap toward sustainable agriculture. With proper policy support and farmer training, nanofertilizers can shape the future of crop nutrition.

Introduction

The increasing pressure on global agriculture to produce more food, feed, and fiber while minimizing the environmental footprint has accelerated the need for innovative, sustainable solutions. Among these, nanofertilizers stand out as a transformative breakthrough. Traditional fertilizers, while effective in increasing yields, suffer from significant inefficiencies, such as low nutrient use efficiency (NUE), environmental degradation, and economic burden on farmers. In contrast, nanofertilizers offer a promising alternative that enhances crop nutrition while supporting ecological sustainability.

Nanofertilizers are fertilizers that are engineered at the nanoscale to ensure better nutrient delivery and absorption by plants. They can be in the form of nanoparticles themselves or can encapsulate nutrients, allowing for a controlled and targeted release. These characteristics make nanofertilizers an essential part of future-ready agriculture, especially for countries like India, where sustainable intensification of agriculture is imperative.

The Need for Nano Fertilizers

The global population is projected to increase by nearly 2 billion people by 2050, demanding a 70% rise in food production. However, agricultural systems are currently grappling with:

- Land degradation and declining soil health
- Nutrient imbalances due to overuse of chemical fertilizers
- Water scarcity and climate change-induced stress
- Food insecurity, especially in developing countries

In India, these challenges are particularly pronounced. With 18% of the world's population but only 4% of global water resources, the country faces acute water stress. Moreover, over 30% of India's land is degraded, and the excessive reliance on conventional fertilizers has led to declining soil fertility, micronutrient deficiencies, and pollution of surface and groundwater. The imbalance in NPK usage—especially the overuse of nitrogen—has further worsened soil health, affecting long-term productivity.

According to the FAO, traditional fertilizers like nitrogen (N), phosphorus (P), and potassium (K) have a nutrient use efficiency of only 30-50%, meaning more than half of the nutrients applied are lost due to volatilization, leaching, runoff, and poor uptake. These inefficiencies not only reduce crop yield potential but also pollute water bodies, degrade soils, and harm beneficial soil organisms.

Nanofertilizers offer a viable solution to address these issues. In the Indian context, their adoption can potentially reduce the usage of chemical fertilizers by up to 50%, while maintaining or even improving crop yields. Innovations such as IFFCO's Nano Urea—already being field-tested and distributed—exemplify how nanotechnology can transform Indian agriculture by enhancing nutrient use efficiency, reducing costs for farmers, and minimizing environmental damage. As India aims to double farmers' income and ensure food security for its growing population, nanofertilizers are poised to play a pivotal role in achieving sustainable agricultural growth.

Types and Applications of Nanofertilizers

Nanofertilizers are categorized based on their content and formulation techniques:

1. Nanoformulations of Macronutrients: Nitrogen, phosphorus, potassium.
2. Nanoformulations of Micronutrients: Zinc, iron, manganese, etc.
3. Nutrient-loaded Nanomaterials: Carriers like zeolites, chitosan, montmorillonite, and silica used for encapsulating nutrients.

Mode of Action

Nanofertilizers release nutrients in a slow and sustained manner, matching plant requirements at various growth stages. Their small size (less than 100 nm) enhances mobility and penetration into plant tissues, whether applied via foliar spray or soil drenching.

Some notable applications:

- Nano-urea improves nitrogen uptake and reduces atmospheric loss.
- Nano-hydroxyapatite acts as a slow-release phosphorus source.
- Potassium nanofertilizers, developed with chitosan-alginate beads, improve drought tolerance and biomass accumulation.

Synthesis and Delivery Technologies

Nanofertilizers can be synthesized using:

- Top-down approaches (e.g., ball milling)
- Bottom-up approaches (e.g., precipitation, coacervation)
- Biological methods using microorganisms or plant extracts

Encapsulation technologies include:

- Nano-coating: Coating conventional fertilizers with polymers or inorganic nanomaterials.
- Nanoemulsions: Liquid-based fertilizers stabilized by surfactants.
- Controlled-release carriers: Using biodegradable polymers (like polyvinylpyrrolidone or chitosan) to release nutrients in response to soil moisture or plant demand.

These technologies ensure precision farming, allowing site-specific nutrient delivery and minimal loss, thereby increasing efficiency and reducing environmental impact.

Advantages of Nanofertilizers

1. Higher Nutrient Use Efficiency (NUE):
 - Reduces the frequency and amount of application.
 - Facilitates synchronized nutrient release based on plant needs.
2. Environmental Sustainability:
 - Minimizes leaching and runoff.
 - Lessens eutrophication and air pollution.
3. Improved Crop Yield and Quality:
 - Boosts photosynthesis, root growth, and resistance to abiotic stress.
 - Enhances nutritional quality (e.g., higher protein and micronutrient content).
4. Cost-Effectiveness:
 - Reduced quantity needed compared to conventional fertilizers.
 - Lower transportation and storage costs.

For example, nano-nitrogen fertilizer increased sugarcane yield by 76%, while nano-zeolite significantly improved the nutrient retention and yield in strawberry and maize.

Advantages of Nano Fertilizers Over Conventional Fertilizers

Aspect	Conventional Fertilizer	Nano Fertilizer
Nutrient Loss	High (leaching, runoff)	Low (controlled release)
Environmental Impact	High (pollution, soil degradation)	Low (eco-friendly release)
Nutrient Use Efficiency	~30–40%	~70–90%
Crop Yield Impact	Moderate	High
Soil Health	Can degrade over time	Supports microbial activity

Challenges and Concerns

Despite their advantages, nanofertilizers are not free from challenges:

- Regulatory and safety concerns: Lack of uniform global standards for toxicity, usage, and labeling.
- Ecotoxicology: Potential long-term effects on soil microbial communities and non-target organisms are still under study.
- Scalability and affordability: High initial investment and lack of mass-scale production units can hinder widespread adoption.
- Farmer awareness: Knowledge gaps among farmers regarding application and benefits need to be addressed through training and extension services.

Future Prospects and Policy Implications

With growing emphasis on climate-smart agriculture, nanofertilizers can become a crucial pillar of sustainable intensification. In India, for instance, Nano Urea developed by IFFCO has already reached field trials and is being rapidly adopted, signaling a shift in national policy support toward nanotechnology in agriculture.

Future developments may include:

- Integration with smart sensors and AI-based platforms for precision nutrient management.
- Development of multi-nutrient nanofertilizers customized for specific crops and soil types.
- Bio-nanofertilizers combining microbial inoculants and nanomaterials for synergistic effects.

Policy frameworks must be evolved to support:

- Subsidies for nanofertilizer development and trials
- Certification and monitoring guidelines
- Inclusion of nanofertilizers in national fertilizer recommendation systems

Conclusion

Nanofertilizers represent a scientific and strategic shift toward efficient, eco-friendly, and economically viable agriculture. By improving nutrient use efficiency, enhancing crop productivity, and minimizing environmental degradation, they offer a robust tool to achieve sustainable development goals (SDGs) such as zero hunger, clean water, and climate action.

However, successful implementation depends on interdisciplinary research, farmer awareness, and policy support. With the right investments in education, innovation, and regulation, nanofertilizers can indeed become the future of crop nutrition.

Cow Dung and Its Role in Plant Growth-Promoting Rhizobacteria (PGPR) for Sustainable Agriculture: A Comprehensive Study



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Abstract

The sustainable intensification of agriculture requires innovative approaches to maintain soil fertility, enhance crop productivity, and reduce environmental impacts. Cow dung, a cornerstone of Vedic agricultural practices, is increasingly recognized as a rich source of nutrients and a carrier for plant growth-promoting rhizobacteria (PGPR). PGPR are beneficial soil microbes that enhance plant growth through nutrient mobilization, phytohormone production, biocontrol of pathogens, and stress mitigation. This paper presents a comprehensive review of cow dung's composition, its microbial diversity, mechanisms of PGPR-mediated plant growth promotion, and practical applications in agriculture. Furthermore, it integrates ancient agricultural wisdom with modern microbial biotechnology, demonstrating how cow dung can serve as a sustainable, eco-friendly, and cost-effective input for contemporary agriculture.

Keywords: Cow dung, Plant Growth-Promoting Rhizobacteria, PGPR, Sustainable Agriculture, Biofertilizer, Soil Microbiome, Vedic Agriculture

1. Introduction

Agricultural sustainability is challenged by excessive use of chemical fertilizers, which disrupt soil microbial communities, degrade soil structure, and lead to environmental contamination. Consequently, organic inputs, particularly those with microbial enrichment potential, are gaining attention as environmentally responsible alternatives.

Cow dung has held a special place in Indian agriculture for millennia. Classical texts such as the Vrikshayurveda and Agricultural Sutras of Vedic Period describe cow dung not only as a nutrient source but also as a medium to enhance soil vitality and microbial activity. Modern studies confirm these claims, identifying cow dung as a complex bio-resource containing organic matter, micronutrients, and a rich microbial community. Among these microbes, PGPR play a critical role in enhancing plant growth, yield, and resilience to biotic and abiotic stress.

This paper explores the multifaceted roles of cow dung in agriculture, emphasizing its interaction with PGPR and highlighting its relevance for contemporary sustainable farming systems.

2. Chemical and Microbial Composition of Cow Dung

2.1 Chemical Composition

Cow dung is a heterogeneous mixture containing organic and inorganic constituents essential for plant growth:

Organic Matter: 20–30%

Nitrogen (N): 1–2%

Phosphorus (P₂O₅): 0.5–1%

Potassium (K₂O): 1–2%

Secondary Nutrients: Calcium, Magnesium, Sulfur

Micronutrients: Zinc, Iron, Copper, Manganese

Additionally, cow dung contains humic and fulvic acids that enhance nutrient retention, soil structure, and microbial activity.

2.2 Microbial Profile

Cow dung harbors diverse microbial communities including:

Nitrogen-fixing bacteria: Rhizobium, Azotobacter, Azospirillum

Phosphate-solubilizing bacteria: Bacillus, Pseudomonas

Actinomycetes: Streptomyces spp.

Fungi: Trichoderma, Penicillium

Other beneficial microbes: Lactobacillus, Micrococcus

These microbes contribute to nutrient cycling, disease suppression, and plant growth promotion. Traditional Vedic texts also mention “Krimis” (microorganisms) in organic matter, highlighting their observed role in soil fertility centuries ago.

3. Plant Growth-Promoting Rhizobacteria (PGPR) and Mechanisms of Action

PGPR are bacteria that colonize plant roots and promote growth through direct and indirect mechanisms.

3.1 Direct Mechanisms

1. Biological Nitrogen Fixation (BNF):

Nitrogen-fixing bacteria (e.g., Rhizobium, Azospirillum) convert atmospheric N₂ into ammonia, supplying essential nitrogen to plants. Cow dung serves as a carrier and nutrient source, enhancing bacterial survival and efficiency.

2. Phosphate Solubilization:

Phosphate-solubilizing bacteria produce organic acids, solubilizing insoluble phosphates in soil for plant uptake.

3. Phytohormone Production:

PGPR synthesize phytohormones such as:

Indole-3-acetic acid (IAA): Promotes root elongation and branching

Gibberellins: Stimulate shoot elongation

Cytokinins: Enhance cell division and nutrient mobilization

4. Siderophore Production:

PGPR produces siderophores, which chelate iron from soil minerals, improving iron availability to plants and limiting pathogenic microbes.

3.2 Indirect Mechanisms

1. Biocontrol of Pathogens:

PGPR secrete antibiotics, hydrogen cyanide (HCN), and lytic enzymes that suppress plant pathogens such as Fusarium, Pythium, and Rhizoctonia.

2. Induced Systemic Resistance (ISR):

PGPR trigger plant defense pathways, enhancing resistance to biotic and abiotic stresses.

3. Stress Tolerance Enhancement:

Certain PGPR synthesize osmolytes and antioxidant enzymes, improving plant tolerance to salinity, drought, and heavy metals.

4. Cow Dung as a Carrier and Stimulator of PGPR

Cow dung not only supplies nutrients but also serves as a microbial carrier and growth enhancer for PGPR.

4.1 Nutrient-Rich Medium for PGPR

The rich organic matter in cow dung supports microbial colonization and survival. Humic substances provide both a food source and stimulatory effect for microbial activity.

4.2 Carrier for Biofertilizers

Cow dung-based composts or vermicomposts can be inoculated with PGPR strains to produce biofertilizers. These formulations enhance microbial stability and efficiency when applied to soils.

4.3 Soil Structure Enhancement

Cow dung improves soil texture, porosity, water retention, and aeration, creating an ideal environment for PGPR colonization and activity.

4.4 Synergistic Microbial Interactions

Microbes in cow dung interact synergistically with native soil microflora, promoting nutrient cycling, suppressing pathogens, and increasing microbial biodiversity.

5. Traditional Knowledge and Modern Validation

Vedic texts such as Vrikshayurveda describe cow dung as an essential soil amendment that “nourishes the plants and strengthens the soil.” Modern science confirms:

Enhanced microbial biomass in cow dung-amended soils

Increased enzyme activities (urease, phosphatase, dehydrogenase)

Improved nutrient mineralization and bioavailability

This convergence of traditional wisdom and modern microbiology underscores the scientific basis of ancient agricultural practices.

6. Application of Cow Dung-Based PGPR in Modern Agriculture

6.1 Crop Yield Enhancement

Legumes: Vermicompost with *Rhizobium* and *Azotobacter* enhances nodulation and nitrogen fixation.

Vegetables: Cow dung compost with *Pseudomonas fluorescens* suppresses *Fusarium* and promotes growth in tomato and brinjal.

Cereal Crops: Maize and wheat respond positively to cow dung biofertilizer inoculated with *Bacillus* and *Azospirillum*.

6.2 Soil Health Improvement

Increased soil organic carbon

Enhanced microbial diversity and enzyme activity

Improved nutrient cycling and availability

6.3 Environmental Benefits

Reduced chemical fertilizer use

Lower greenhouse gas emissions

Mitigation of soil and water pollution

7. Case Studies

1. India: Application of cow dung-based biofertilizers increased wheat yield by 18–25% over chemical fertilizers.

2. South Korea: Cow dung inoculated with phosphate-solubilizing bacteria enhanced phosphorus availability and vegetable growth.

3. Brazil: Integrated cow dung compost and PGPR improved maize productivity, microbial biomass, and soil fertility.

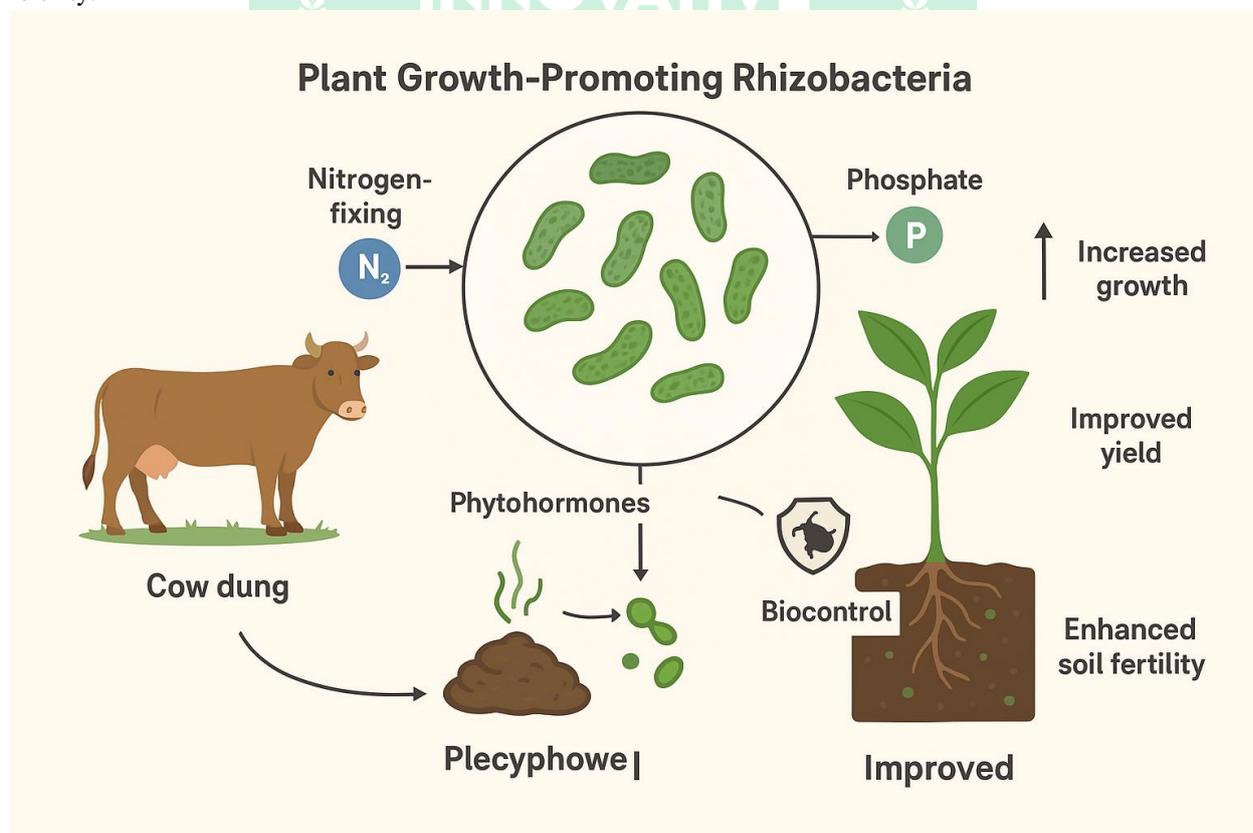


Fig 1: Plant growth promoting rhizobacteria and cow dung

8. Challenges and Future Prospects

8.1 Challenges

Standardization of microbial inoculants

Ensuring pathogen-free cow dung

Compatibility with mechanized large-scale farming

Seasonal variation in cow dung microbial populations

8.2 Future Directions

Development of stable, ready-to-use cow dung-based biofertilizers

Metagenomic studies of cow dung microbiome for PGPR discovery

Field trials across diverse agroecological zones

Integration with precision agriculture and organic farming systems

9. Conclusion

Cow dung is a potent natural resource that promotes sustainable agriculture through its synergistic interaction with PGPR. Beyond its role as a nutrient source, cow dung enhances microbial activity, improves soil structure, and supports plant growth under diverse environmental conditions. Its integration into modern farming systems aligns with both ancient Vedic agricultural wisdom and contemporary microbial biotechnology, providing a low-cost, eco-friendly, and effective strategy to improve soil health and crop productivity.

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Building Resilience: Adaptive Agricultural Practices for El Niño and La Niña



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Abstract

The El Niño-Southern Oscillation (ENSO) cycle significantly impacts global agriculture through extreme weather patterns, with El Niño causing droughts and La Niña bringing excessive rainfall and flooding. This study examines adaptive agricultural practices essential for building resilience against these climate phenomena. Key strategies include adopting drought-tolerant and flood-resistant crop varieties, implementing advanced water management systems including smart irrigation and rainwater harvesting, and enhancing soil health through conservation practices. Technology integration through early warning systems and precision agriculture enables proactive decision-making, while financial instruments and government support provide economic protection. Regional examples demonstrate diverse adaptation approaches, from indigenous seed varieties in Africa to climate-smart agriculture frameworks globally. These multifaceted strategies combining traditional knowledge with modern technology are crucial for maintaining agricultural productivity and food security under increasing ENSO variability.

Introduction

The El Niño-Southern Oscillation (ENSO) cycle represents one of the most powerful climate phenomena affecting global agriculture today. These periodic fluctuations in Pacific Ocean temperatures create far-reaching weather disruptions that can devastate farming communities worldwide. El Niño typically brings droughts, extreme heat, and water scarcity, while La Niña often delivers excessive rainfall, flooding, and cooler temperatures. As climate change intensifies these effects, building agricultural resilience through adaptive practices has become essential for securing food production and protecting rural livelihoods.

Understanding ENSO's Agricultural Impact

El Niño events occur every two to seven years when warming Pacific waters alter global weather patterns, typically reducing rainfall in major agricultural regions like Southeast Asia, parts of South America, and sub-Saharan Africa. The 2015-2016 El Niño, one of the strongest on record, caused widespread drought that reduced maize yields across southern Africa and impacted rice production throughout Asia.

Conversely, La Niña strengthens trade winds and cools ocean temperatures, often increasing rainfall in many regions but creating risks of flooding and waterlogging. While La Niña can benefit crop production through improved soil moisture, excessive precipitation can destroy harvests, delay planting schedules, and create conditions favourable for pests and diseases.

Crop Diversification and Climate-Resilient Varieties

Adopting Stress-Tolerant Varieties

The foundation of ENSO resilience lies in selecting appropriate crop varieties. During El Niño years, drought-tolerant cultivars become crucial. The Indian Council of Agricultural Research (ICAR) has developed high-yielding, drought-resistant varieties of rice, maize, and sorghum that can withstand water stress and thrive in low-rainfall conditions. These varieties require less water while maintaining productivity, making them ideal for drought-prone regions.

For La Niña conditions, flood-tolerant varieties are essential. The Philippine Rice Research Institute has identified six rice varieties capable of surviving up to two weeks of submergence, enabling farmers to maintain yields even during severe flooding events. Similarly, water-resistant rice varieties have been successfully introduced to frequently flooded plains, demonstrating the value of targeted variety selection.

Diversification Strategies

Crop diversification reduces vulnerability by spreading risk across multiple species with different climate tolerances. Research in Zambia shows that while maize struggles under El Niño-induced drought, leguminous crops like Mucuna, lablab, cowpea, and groundnuts exhibit remarkable resilience, thriving in adverse conditions and providing crucial sources of food, feed, and income. Integrating drought-resistant crops like cassava alongside traditional staples offers additional security. Cassava's exceptional drought tolerance makes it a promising alternative for regions experiencing erratic rainfall patterns, providing a reliable food source when other crops fail.

Advanced Water Management Techniques

Smart Irrigation and Water Conservation

Efficient water management forms the cornerstone of ENSO adaptation. Smart irrigation systems using sensors and data analytics optimize water usage, reducing waste during El Niño droughts while managing excess water during La Niña floods. Drip irrigation has become mandatory for sugarcane cultivation in Maharashtra and Karnataka, states comprising 27% of India's sugarcane area, demonstrating government commitment to water efficiency.

Rainwater Harvesting and Storage

Rainwater harvesting systems capture and store precipitation during abundant periods, providing reserves for dry spells. These systems include constructing pans, water holes, dams, and collecting runoff from roads. The Indian government's Pradhan Mantri Krishi Sinchai Yojana (PMKSY) and related schemes support such infrastructure development to ensure farmers have water access even during droughts.

Soil Health and Conservation Practices

Building Soil Resilience

Healthy soils serve as the foundation for climate-resilient agriculture. Conservation tillage practices, including no-till and reduced-till farming, preserve soil moisture and structure while reducing erosion. These techniques are particularly valuable during El Niño droughts, as they help retain limited water resources in the soil profile. Soil organic carbon enhancement through improved management practices strengthens agricultural systems' ability to withstand climate extremes. Research from Bali demonstrates that vegetation recovery during La Niña significantly enhanced soil organic carbon sequestration, with a 43.80% increase observed from 2015 to 2022. This improvement coincided with decreased land surface temperatures, highlighting the interconnection between soil health and climate resilience.

Integrated Nutrient Management

Combining organic and inorganic fertilizers, farmyard manure, vermicompost, and crop residues maintains soil fertility while building long-term resilience. Organic fertilizers particularly help increase soil fertility and plant resistance to drought, making them valuable tools for managing El Niño impacts.

Technology Integration and Early Warning Systems

Climate Information and Forecasting

Early warning systems enable proactive farming decisions through timely weather info. Tamil Nadu Agricultural University's Automated Agro Advisory Service (TNAU AAS) app offers real-time crop guidance, sowing times, and extreme weather alerts. Enhanced by satellite tech and AI, improved ENSO forecasts allow farmers and policymakers better preparation for El Niño and La Niña events.

Precision Agriculture

Modern agricultural technologies, including GPS-guided machinery, soil sensors, and drone monitoring, enable precise resource application and real-time field monitoring. AI and IoT-based farm management systems, like those developed by agricultural technology startups, provide crop-specific irrigation advisory services that can save up to 50% of water usage.

Financial Protection and Institutional Support

Risk Management Instruments

Comprehensive crop insurance schemes provide economic safety nets that encourage adoption of resilient practices. Expanding coverage to include ENSO-related losses protects farmers from climate-induced financial

hardships. Parametric insurance products, which trigger payments based on weather indices rather than actual losses, offer faster compensation during extreme events.

Government Programs and Support

Government initiatives supporting climate-resilient agriculture include subsidies for drought and flood-resistant seeds, technical guidance programs, and improved access to modern machinery. Training programs, such as those conducted by Punjab's government promoting Direct Seeding of Rice (DSR) methods, help farmers adopt water-efficient practices.

Regional Adaptation Examples

Climate-smart agriculture (CSA) integrates adaptive practices like improved crop varieties, efficient water management, soil conservation, and technology to sustainably enhance productivity and resilience while reducing emissions. By combining traditional knowledge with modern tools, CSA equips farming systems to withstand ENSO extremes, secure food security, and support rural livelihoods amid increasing climate variability.

Toward Climate-Smart Agriculture

The integration of adaptive practices within climate-smart agriculture (CSA) offers a holistic solution to ENSO resilience by increasing productivity, enhancing resilience, and reducing emissions. Combining improved crop varieties, water-efficient management, soil conservation, and technology helps farming systems withstand El Niño and La Niña extremes sustainably. Building resilience requires blending traditional knowledge with modern tools through crop diversification, conservation practices, early warning systems, and supportive policies. These strategies are essential for securing food security and sustaining rural livelihoods amid increasing ENSO frequency and climate variability.

Conclusion

The El Niño-Southern Oscillation profoundly impacts global agriculture with alternating droughts and floods. Building resilience through crop diversification, water-efficient practices, soil conservation, early warning systems, and supportive policies is vital. These adaptive strategies are essential for securing food production and rural livelihoods amid increasing climate variability and ENSO intensity.

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The Digital Pollinator: How Drones are Revolutionizing Hybrid Seed Production



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Hybrid seeds are the cornerstone of modern agriculture, responsible for significant yield increases, disease resistance, and improved crop vigor. However, producing these seeds is a labor-intensive and precision dependent process. It requires the controlled transfer of pollen from a designated male parent plant to a designated female parent plant. For centuries, this task has been performed by wind, insects, or human hands. Now, a new, high-tech pollinator is taking to the skies: the unmanned aerial vehicle, or drone (Klein and Kenta, 2020).

Drone pollination is emerging as a transformative solution to the critical challenges of labor scarcity, high costs, and unpredictable natural pollinator populations (Zhou *et al.*, 2021). This article explores the mechanics, benefits, challenges, and future prospects of using drones for hybrid seed production.

The Critical Challenge of Hybrid Seed Production

Hybrid seed production relies on cross-pollination between two genetically distinct parent lines. The female plants are often emasculated (male parts removed) or are male-sterile to prevent self-pollination. This ensures that every seed harvested is a true hybrid.

Traditional methods face significant hurdles:

Labor Intensity: Hand pollination is extremely time-consuming and requires a large, skilled seasonal workforce, which is becoming scarce and expensive globally.

Inefficiency of Natural Methods: Relying on bees or wind is unreliable. It offers no control over pollen purity, leading to contamination and lower quality seeds. Weather conditions can severely disrupt this process.

Scale and Timing: Pollination must occur within a narrow window of a few days when the female flowers are receptive. Scaling up production with manual methods is logistically challenging.

How Drone Pollination Works: A Three-Step Process

Drone pollination is not merely about flying over a field. It is a sophisticated system integrating robotics, biology, and data science (Hiraguri *et al.*, 2023).

Pollen Collection: Drones equipped with specialized attachments first fly over the fields of the male parent plants. They use brushes or suction devices to gently harvest pollen from the flowers. The pollen is collected in a chamber, often under controlled conditions to maintain viability.

Pollen Preparation and Loading: The collected pollen is then processed. It may be mixed with a carrier agent (like lycopodium powder or flour) to increase its volume and ensure smooth flow. This mixture is then loaded into a dispensing system attached to a separate pollination drone.

Precise Pollen Dispensing: The pollination drone, guided by GPS and pre-programmed flight paths, flies over the female parent field. It uses a mechanism such as a rotating brush, a pneumatic blower, or a vibrating sieve to create a cloud of pollen that settles on the female flowers. The altitude, speed, and release rate are calibrated for optimal coverage and minimal waste.

Key Advantages of Drone Pollination:

The adoption of drone technology offers compelling benefits for seed companies and farmers:

Precision and Purity: Drones ensure that only the intended pollen reaches the female plants, drastically reducing contamination and producing higher-purity hybrid seeds.

Massive Labor Savings: A single drone operated by a pilot can pollinate hectares of land in a fraction of the time required by a large manual workforce, addressing the critical labor shortage.

Speed and Scalability: Drones can cover large areas quickly, ensuring that the entire field is pollinated within the crucial short window of female flower receptivity.

Data-Driven Insights: Drones can be equipped with multispectral or hyperspectral cameras to monitor crop health, identify the peak flowering period, and assess pollination success, enabling data-driven decisions for future cycles.

Safety and Accessibility: Drones can easily pollinate tall crops like maize or palm trees without the need for ladders or heavy machinery, improving worker safety.

Current Challenges and Limitations

Despite its promise, the technology is not without challenges:

Pollen Viability: Pollen is delicate. The mechanical process of collection and dispersal can damage pollen grains, reducing their viability. Optimizing methods for different crop species is an ongoing area of research.

Environmental Factors: Wind speed and temperature can significantly affect drone stability and the dispersion pattern of the pollen cloud.

High Initial Investment: The cost of drones, sensors, and the technical expertise required can be a barrier for smaller seed producers.

Regulatory Hurdles: Aviation authorities in different countries have regulations governing drone operations, especially for agricultural spraying/dispersing, which must be navigated.

Case Studies and Real-World Applications

Apples and Pears in China: Researchers have successfully tested drone pollination in fruit orchards. Drones equipped with fluid-dispersing systems released pollen suspensions, resulting in fruit set rates comparable to manual pollination (Zhou *et al.*, 2021).

Maize (Corn): As a wind-pollinated crop with abundant pollen, maize is an ideal candidate for drone pollination. Trials have shown that drones can effectively distribute pollen over male-sterile female lines, promising a more efficient alternative to detasseling and natural wind pollination.

Research in Japan: A team from the National Agriculture and Food Research Organization (NARO) and startup company Dronicon have been pioneers, developing systems specifically for the pollination of crops like strawberries and kiwi, where labor is a major constraint.

The Future Outlook

The future of drone pollination lies in increased autonomy and intelligence. We can expect:

AI-Powered Systems: Drones will use computer vision to identify individual receptive flowers and perform targeted, spot-pollination instead of blanket coverage, maximizing efficiency.

Swarm Technology: Fleets of smaller drones working in coordination could pollinate vast fields simultaneously with even greater precision.

Integration with Farm Management Software: Pollination data will be integrated with other agronomic data to create a holistic view of the crop production cycle.

Conclusion:

Drone pollination represents a paradigm shift in agricultural technology. By addressing the fundamental bottlenecks of hybrid seed production, it holds the potential to enhance global food security by making the production of high-yielding seeds more efficient, reliable, and scalable. While technical challenges remain, the rapid pace of innovation suggests that the sight of drones buzzing purposefully over seed fields will soon become a common and vital feature of modern agriculture.

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Drone Technology in Agriculture



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The Agricultural Drone Revolution

The agriculture industry has entered a new era, one where drones and unmanned aerial vehicles (UAVs) are revolutionizing everything from crop monitoring to resource management. As agricultural drone technology advances, the integration of these innovative systems is transforming traditional farming practices, driving significant improvements in efficiency, precision, and sustainability across a range of applications.

1. Precision Spraying & Variable Rate Application: Drone Spraying Systems for Efficient Farming

Drone spraying systems are among the most game-changing agricultural innovations. These advanced unmanned aerial vehicles (UAVs) deliver targeted applications of pesticides, herbicides, and fertilizers directly to crops, providing precise coverage that bulk ground-based methods cannot match.

How it Works:

- Advanced sensors analyse crop health, mapping areas that require specific chemical treatments.
- Variable rate application ensures each plant gets the exact amount needed, reducing chemical usage by 30–40%.
- Drones fly low and steady, reaching hard-to-access or waterlogged areas quickly and safely—no need for heavy tractors.

The result shows Uniform coverage across diverse terrains, minimized environmental impact, and decreased operational costs for farmers. By limiting over-application, farms see economic gains while protecting soil health and nearby water sources from chemical runoff.

2. Soil and Field Analysis: Drone Soil Analysis for Precision Farming

Understanding soil conditions is a fundamental aspect of precision agriculture. Drone soil analysis leverages multispectral and hyperspectral sensors to provide detailed insights into soil nutrient levels, moisture content, pH balance, and other factors. Accurate data enables farmers to:

- **Optimize fertilization strategies** (right place, right time, right quantity)
- **Analyse 3D maps** of farmlands for improved planning of planting patterns, irrigation systems, and field management
- **Track changes** in soil health over time, guiding regenerative farming practices

3. Drone Irrigation Management: Conserving Water & Enhancing Crop Yields

Efficient irrigation management is more crucial than ever—especially in drought-prone regions. Drone technology in agriculture now utilizes thermal and multispectral sensors to identify areas within fields requiring more or less water. With drone irrigation management, we can:

- **Detect under-watered patches** via heat signatures and vegetation analysis
- **Plan irrigation system layouts** using high-resolution maps
- **Conserve water resources**, reduce operational costs, and support environmental sustainability

4. Automated Planting and Seeding: Enhancing Crop Distribution

Automated drone planting systems use advanced flight planning and sensors to drop seeds at perfect intervals and depths. This technology offers:

- **Even crop growth** and stronger plants through precise seed spacing and deployment
- Minimal seed waste, reducing costs per acre
- **Ability to plant** in terrains difficult or impossible to cultivate with traditional machinery (steep slopes, marshy fields)

These innovative solutions support reforestation, cover cropping, and introducing new crops efficiently across diverse areas.

5. Livestock Monitoring: Drones Enhance Herd Health & Management

Grazing animals over vast rangelands is resource-intensive and laborious. Drones in agriculture now come equipped with high-resolution cameras, thermal imaging, and smart tracking algorithms—allowing us to:

- **Pinpoint livestock locations**, even in rugged or remote areas
- **Monitor animal health** and quickly identify distress or illness (e.g., a cow separated from its group or non-grazing behaviour)
- **Conduct accurate herd counts and keep real-time digital inventories**

6. Plant Disease Assessment: Early & Accurate Detection with UAVs

How can we stop crop diseases before they devastate our yield? This is where drones in agriculture shine, using multispectral, visible, and infrared sensors to identify disease symptoms often before visible signs appear to the human eye.

- **Spot early-stage infections**, including fungal and bacterial diseases
- Apply targeted corrective actions only where needed (avoiding unnecessary broad-spectrum spraying)
- **Minimize crop loss** by containing outbreaks swiftly

Overcoming Challenges & The Future of Drone Technology in Agriculture

While the benefits of **drone technology in agriculture** are clear, the journey is not without its **challenges**. Key roadblocks include:

- **High initial investment costs**—though prices are dropping, advanced UAVs, sensors, and analytics are still out of reach for some farmers.
- **Technical complexity**—proper training is required to operate, maintain, and interpret **drone data** effectively.
- **Regulatory hurdles**, particularly around cross-border data transfer and use of drones from foreign vendors.
- **Security concerns**—data integrity, protection from cyber threats, and need for transparent, tamper-proof supply chains.

Despite these obstacles, the **future for drones in agriculture** is bright:

- Emerging solutions like [autonomous helicopters for crop spraying](#) and [fully autonomous crop dusting platforms](#) promise to push boundaries even further.
- Cloud computing and AI integration are making drone-generated insights more accessible—even to those without technical expertise.
- Research and development aim to enhance drone autonomy and agile decision-making for precision farming.

Empowerment of Farm Women through Value Addition of Horticultural Crops



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Over the years, there is a gradual realization of the key role of women in agricultural development and their vital contribution in the field of agriculture, food security, horticulture, processing, nutrition, sericulture, fisheries, and other allied sectors. For decades, women have been involved in horticultural crop production namely sowing, harvesting and post-harvest handling. In many agricultural communities, especially in developing countries, women are the backbone of horticultural production but their contributions often unrecognized and their economic potential remains largely untapped. Therefore one of the most effective way to change the scenario of Indian agriculture is through value addition of horticultural crops by farm women. By converting raw produce into processed, marketable goods women can change their role from labourers to entrepreneurs and from cultivators to creators.

Value addition means transforming raw horticultural produce into value added products like jams, jellies, candies, pickles, oil extracted perfumes, ready to eat snacks etc. This not only enhances the shelf life and quality of the produce but also enables higher profitability for small-scale producers. Therefore value addition refers to the process of increasing the economic value and consumer appeal of a product.

Women contribute significantly to horticulture, especially in post harvest activities such as grading, sorting, cleaning and packaging. However they often confined to low-paying labour roles. Due to limited access to education, credit, training and markets, their potential as entrepreneurs' remains underutilized. By engaging women in value-added processing, farm women can be transformed from dependent to self-reliant.

Need for value addition of horticultural crops

India is the third largest producer of food grains after China and USA and second largest producer of fruits and vegetables in the world after China, India could take the first place, but unfortunately, due to poor post-harvest facilities, wastage of food grains, fruits and vegetables which amount to 30 - 40 % India is located at the second place after China.

Food processing brings a wider range of benefits to enterprising rural women as it includes the potential for adding value to basic agricultural produce and dairy which will eventually improve the small-scale women producers and entrepreneur's income-generating activity, allowing improved use and control of local resources and helping to create employment for rural women. It will further contribute to make rural women economically and socio-psychologically empowered.

Benefits of women empowerment through value addition

Economic Empowerment

Value added products fetch higher market prices compared to raw produce. Women can start small scale units at home or in community or FPOs and generate stable income, contributing to family welfare and financial independence.

Empowering women with economically productive work will enhance their contribution to Agriculture and livestock development.

- Access to resource
- Micro-credit programmes
- Access to cooperatives and local women's organizations

Employment Generation

Women led enterprises can create jobs for other rural women, particularly through Self Help Groups (SHGs) and Farmers Producers Organizations (FPOs). This leads to empowerment at community level.

Reduction of Post Harvest Losses

Horticultural crops are highly perishable; processing them into value-added products reduces wastage of produce and increases year-round availability.

Educational Empowerment

Empowering women with the knowledge, skills and confidence enhances full participation in the development process.

Social Empowerment

Equality of treatment, equality of respect, equality of opportunity, equality of recognition and above all equality of status will be provided to women.

Political empowerment of women is basically to create more consciousness among women and to strike a greater gender balance in the decision making.

Technological Empowerment

Capacity Building: Training on food processing, packaging, labeling, hygiene, exposure to Mass Media and social media, market led extension services will help in fostering women's self esteem and leadership capabilities.

Various schemes and organizations are promoting women's involvement in horticultural value addition namely National Horticulture Mission (NHM), Rashtriya Krishi Vikas Yojana (RKVY), Women SHG- based funding by NABARD and capacity building programmes by Krishi Vigyan Kendras (KVKs). These initiatives provide training, financial support, market access and infrastructure for small scale processing units.

Technologies related fruit and vegetable:

Many technologies related to processing of fruits and vegetables can be started with minimum investment and less number of equipment and labour force for profitable business entrepreneurship.

Watermelon rind candy:

Normally watermelon rind is discarded while eating fruits or making juice or when grown for seed purpose. Therefore, watermelon rind can be used as a sweet candy for children which is rich in fiber than the flesh, making it beneficial for digestion. In the preparation of candy part of the water is removed, sugar is incorporated in to the product for 3 days and further dried to optimum level of moisture and packed for marketing.

Vegetable puree:

Technologies for the preparation of culinary products such as tomato, onion, garlic, green chillies, ginger pastes, and tamarind and lime sauces are also available.

Conclusion

Empowering women particularly rural women for the task are a challenge. Women in rural sector can play a crucial role to give a boost in the processing of perishable products at small sector. There is an urgent need to support women managed rural production and marketing ventures in horticulture, and post-harvest processing and to provide technology training and input support to women to take advantage of emerging high-value agribusiness sector. Empowering women is not just a matter of equity- it is a catalyst for sustainable economic growth, food security and rural development. Women led value addition not only boosts income-it also promotes sustainability. Eco-friendly methods, organic certifications and community based enterprises can build resilient rural economies.

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The Age-Based Division of Labor in Honey Bees: The Role of Nurse Bees in Royal Jelly Production



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INTRODUCTION

The secretion of royal jelly is a complex physiological process carried out by young worker honey bees, also known as nurse bees, typically 6 to 15 days old. Royal jelly is a highly nutritious substance produced by the bees' hypopharyngeal and mandibular glands.

In a honey bee colony, a nurse bee is a young, female worker bee whose primary role is to feed and care for the developing larvae and the queen. This specialization is a key part of the honey bee's age-based division of labor, known as temporal polyethism, where a bee's duties change as it matures.

Characteristics of nurse bees

- **Age:** Worker bees typically become nurse bees for about one to two weeks, usually from day 3 to day 12 of their adult lives.
- **Physiology:** During this period, their hypopharyngeal glands, located in their head, are fully developed and able to produce royal jelly. These glands begin to atrophy as the bee gets older and takes on other roles.
- **Location:** Nurse bees perform their duties deep inside the hive, in the brood nest area where the queen lays eggs.

Duties of a nurse bee

- **Feeding larvae:** Nurse bees produce and secrete royal jelly, a milky, protein-rich food that they feed to all young larvae for their first few days of life. For larvae destined to become queen bees, the nurse bees continue to provide royal jelly throughout their development.
- **Caring for the queen:** Nurse bees attend to the queen, feeding and grooming her. By doing so, they also help spread the queen's pheromones throughout the hive, which signals that a healthy queen is present.
- **Colony health:** Their meticulous care of the young is vital for the health and growth of the colony. Nurse bees visit larvae frequently—as many as 1,300 times per day—to feed and inspect them.

Transition to other roles

As a nurse bee ages, her glands for producing royal jelly decrease in size, and she moves on to other tasks within the hive before becoming a foraging bee. This division of labor is flexible; if a hive has a shortage of nurses, older bees can temporarily revert to the role to prevent a breakdown in the colony.

Steps involved in the secretion of royal jelly

Step 1: Consumption of pollen and honey

The process begins with nurse bees consuming large amounts of pollen and honey.

- **Pollen:** Provides the high protein content necessary for glandular activity. The quality and type of pollen affect the composition of the royal jelly produced.
- **Honey:** Supplies the carbohydrates that fuel the bees' metabolism and provide energy for the synthesis of the jelly's complex components.

Step 2: Metabolism and synthesis in the glands

The components from the digested pollen and honey are metabolized to create the precursors of royal jelly.

- **Hypopharyngeal glands (HGs):** These glands in the nurse bee's head are primarily responsible for synthesizing and secreting the protein-rich, water-soluble portion of royal jelly. This includes the Major Royal Jelly Proteins (MRJPs), which constitute most of the jelly's protein content. HGs are most active during the nurse bee stage and shrink as the bee ages.

- **Mandibular glands (MGs):** These glands secrete the lipid-based components, including the unique fatty acid 10-hydroxy-2-decenoic acid (10-HDA), which are then blended with the HG secretions.

Step 3: Mixing and secretion

The protein and lipid secretions are combined to form the final, milky-white substance.

- The two separate secretions are blended in a cavity within the nurse bee's head.
- The nurse bee then regurgitates the finished royal jelly.

Step 4: Provisioning of larvae and the queen

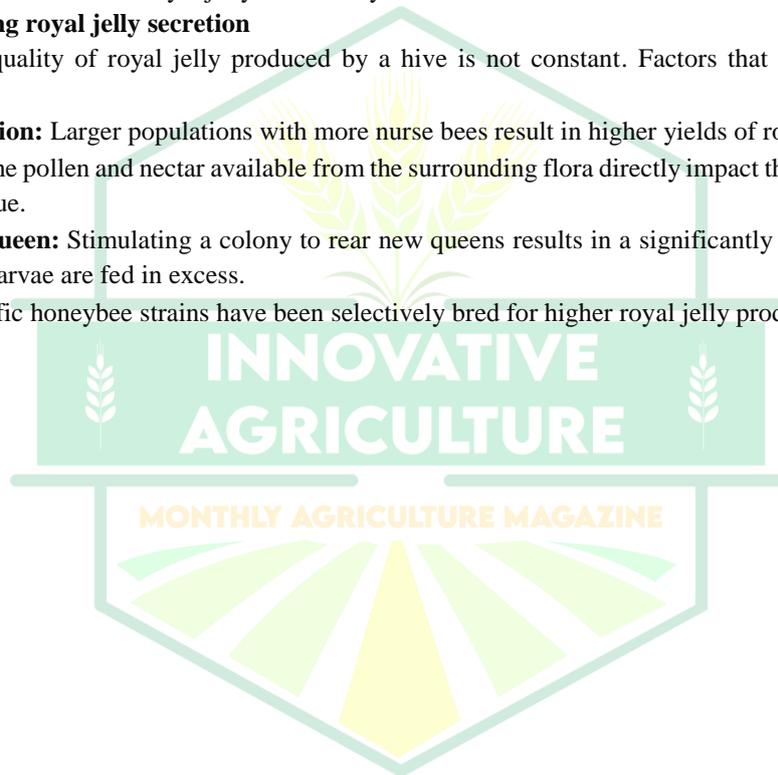
The final step is the feeding of the royal jelly to the colony.

- All young larvae receive royal jelly for their first two to three days of life.
- For larvae destined to become worker bees, the diet is changed after the third day to a less nutritious "worker jelly".
- However, for larvae being raised to become queens, the diet of pure royal jelly continues throughout their entire larval development.
- Adult queen bees are also fed royal jelly exclusively for the rest of their lives.

Factors influencing royal jelly secretion

The amount and quality of royal jelly produced by a hive is not constant. Factors that influence production include:

- **Colony population:** Larger populations with more nurse bees result in higher yields of royal jelly.
- **Food source:** The pollen and nectar available from the surrounding flora directly impact the jelly's composition and nutritional value.
- **Presence of a queen:** Stimulating a colony to rear new queens results in a significantly higher production of royal jelly, as the larvae are fed in excess.
- **Genetics:** Specific honeybee strains have been selectively bred for higher royal jelly production



Beeswax rendering: a step-by-step guide to purifying wax from honeycomb



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Introduction

Beeswax

Beeswax is the material that bees use to build their nests. It is produced by young honeybees that secrete it as a liquid from special wax glands. Worker bees secrete wax when they are 14 to 18 days old. On contact with air, the wax hardens and forms scales, which appear as small flakes of wax on the underside of the bee. About one million wax scales make 1 kg of wax. Bees use the wax to build the well-known hexagonal cells that make up their comb, a very strong and efficient structure. Bees use the comb cells to store honey and pollen; the queen lays her eggs in them, and young bees develop in them. Beeswax is produced by all species of honeybees, although the waxes produced by different species have slightly different chemical and physical properties. In India, major proportion of wax is from combs of *Apis dorsata*.

Uses of wax

- Mainly used by candle industry
- Used for preparing comb foundation sheets
- Used in cosmetics like cold creams, lipsticks and rouges
- Used in pharmaceutical and perfume industry (ointments, capsules, pill coating and deodorants)
- Used for preparing shoe polish, furniture etc. for water proofing
- Used in adhesives, chewing gums and inks etc.

To extract wax from a honeycomb, you can use a simple hot water melting method. The process involves gently melting the honeycomb in water, straining out impurities and allowing the pure beeswax to solidify.

Materials required

- Honeycomb (cappings or old comb)
- Large, old pot (do not use a pot you want to cook with again)
- Double boiler (or a heat-safe jar and a pot)
- Water
- Strainer or several layers of cheesecloth
- Heat-safe container or mold for the wax
- Stirring utensil
- Heat-resistant gloves

Wax is extracted from honeycomb by first separating the honey, then melting and straining the leftover comb. For best results, use a double boiler to avoid overheating the wax, and dedicate kitchen tools specifically for this process, as beeswax is difficult to clean.

Step 1: Extract the honey

If you are starting with honeycomb that still contains honey, you must first separate the honey.

1. **Cut the comb:** Use a sharp knife to cut the honeycomb into smaller, manageable pieces.
2. **Crush the comb:** Place the pieces in a large bowl and crush them with a potato masher or spoon to break open the hexagonal cells.

3. **Strain:** Put the crushed comb into a fine mesh strainer or cheesecloth-lined colander placed over another container. The honey will slowly drip out over several hours, leaving behind the beeswax and other debris. To speed up the process, you can gently massage or squeeze the cheesecloth.

Step 2: Melt the beeswax

After the honey is removed, you will be left with a mixture of beeswax and debris.

Prepare the honeycomb. Start by removing as much liquid honey as possible, using a crush-and-strain method if necessary. Break the honeycomb into smaller pieces and place them in your designated pot.

1. **Fill your pot:** Place the leftover beeswax and debris into the top pot of a double boiler or a large saucepan. Add enough water to cover the wax completely. A ratio of 1 part wax to 2 parts water works well.

2. **Heat gently:** Place the double boiler on the stove and heat over low-to-medium heat. The goal is to melt the wax slowly and consistently without scorching it, which can happen with direct, high heat. The ideal temperature is between 145°F and 160°F (about 63–71°C).

3. **Monitor the melt:** Stir the mixture occasionally to help the wax melt evenly. The wax will melt and rise to the surface of the water, while debris and impurities will sink to the bottom.

Cool and remove the wax. Once the wax has completely melted, remove the pot from the heat and allow it to cool completely. As it cools, the beeswax will solidify into a disc or "puck" on top of the water.

Lift the wax cake. Once the wax is hard, use a butter knife to loosen it from the edge of the pot and lift it out. The bottom of this wax cake will likely be dirty with honey, pollen, and debris. Scrape off this layer with a knife.

Step 3: Strain and cool the melted wax

Prepare for a second melt. To make the wax cleaner, you will need to melt it again using a double boiler to avoid direct heat. Place the wax cake into the top pot of your double boiler or into a heat-safe glass jar and place it in a pot of water.

Melt the wax again. Gently heat the water, melting the wax until it is completely liquid. Be careful not to let any water get into the wax.

1. **Prepare the strainer:** Place a clean, fine mesh strainer or new cheesecloth over a heat-safe container, such as a glass jar or old bucket.

2. **Strain:** Carefully pour the hot, melted wax and water mixture through the filter. The filter will catch any remaining large impurities, such as pollen, cocoon particles, and propolis.

3. **Cool:** Let the mixture cool completely. As it cools, the beeswax will solidify into a disc on top of the water. Debris that was small enough to pass through the filter will settle on the underside of the wax disc.

Step 4: Finishing, Purifying and storage the beeswax

1. Your initial block of wax will likely still have some impurities. A second melt will produce a cleaner product.

2. **Release from the mold.** Once completely cool and solid, you can pop the beeswax out of the mold. Silicone molds are particularly good for this as they are flexible and easy to use.

3. **Remove the wax disc:** Once the wax has fully hardened, run a knife around the edges to loosen it and lift the disc out of the container.

4. **Scrape the bottom:** Scrape any residue off the bottom of the disc with a knife.

5. **Perform a second melt:** Repeat the melting process in a double boiler, but this time, you can melt the wax alone or with fresh, soft water.

6. **Final filter:** For a very pure product, pour the melted wax through a finer filter, such as a coffee filter, and into your final molds. Silicone muffin tins and other heat-safe, non-stick molds work well for creating easy-to-store blocks.

7. **Let it harden:** Allow the wax to cool and harden in the molds. The final, pure beeswax is ready to be used for candles, cosmetics, polishes, and more.

8. **Store the wax.** Store your new, clean beeswax in a cool, dry place until you are ready to use it for candles, cosmetics, or other projects.

Dry Flower: A Promising Floriculture Industry



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Value addition to floriculture material is a most promising area. In this dry flower are known for their everlasting nature. This dry flower industries experiencing substantial growth in recent years, which is driven through increase in the demand in both national and international market. There are promising opportunities for dry flower industry in India. Dry flowers once considered as a traditional decoration method, now it is comeback as a trendy, versatile and sustainable value-added product. In India this industry is valued for Rs.100 crores annually, with this economic growth it is also providing employment opportunities to more than 15000 people. In India dry flower industry growing in an annual rate of 8-10%. India is exporting 500 different varieties of flower to nearly 20 countries. USA and UAE are the major countries importing India dry flower products. This dry flower industry brought to India by British. It is almost five-decade old industry. Most concentrated area of dry flower preparation is in states of Tamil Nadu, West Bengal, Andhra Pradesh and Karnataka. When we see some of the advantages of dry flowers are, long lasting, available through out the year, ecofriendly, bio degradable, job opportunities, most 80% flowers species can be dried.

Major advantages of dry flower industry are unlike fresh flowers dry flowers offers longevity and sustainability. Their look is very appealing and are ecofriendly in nature. Dry flowers offer versatility and aesthetic appeal because these flowers can be used in more creative ways in different events. The most important thing of dry flower is they are very cost-effective, one-time purchase lasts significantly longer. Unlike fresh flower dry flowers are available through out the year and are not subjected to seasonality. With these advantages dry flowers are used in wedding and event industry, home décor, Handcraft products, dried flower subscription.

Drying Techniques:

Various methods are employed to drying flowers and foliage. The method adopted for drying depends on the character of the plant, whether the plant is succulent or not succulent, hardy or delicate in nature.

a) Air drying

Air drying flowers is one of the easiest methods of flower and foliage preservation and gives a crisp look that lasts for years. Air drying is commonly referred as the “hang and dry” method. It is the oldest and easiest drying technique. The stems of flowers and their foliage are tied and hung upside down. The rooms should be warm, dark and dry with good air circulation. It is one of the longest drying methods. Usually, it takes three to four weeks for the flowers to dry completely.

b) Water drying

Water drying is a method of preserving in which the flower along with stem devoid of leaves are placed in five centimetres of water. This is then, placed in a warm place, out of direct sunlight. The water is absorbed and evaporates as the flower dries. Flowers which are suitable for water drying are hydrangeas, heathers, hybrid delphiniums, acacia, gypsophila, bells of Ireland, proteas.

c) Press drying:

One of the most popular methods for drying flowers is to put them under pressure, to remove the moisture out, leaving the color of the flowers and structure unaffected. The easiest method is placing them in heavy books or between newspaper and allow for drying. Pressed flowers are especially suitable for flower pictures, as well as decoration on note paper, place cards etc.

d) Drying by embedding in desiccants:

A desiccant is simply a substance with a high affinity for water which can be used as a drying agent. This is most commonly used method and many consider it the best all-around method. Several materials are used as drying

agents. Most well-known is silica gel and borax but clean dry sand can also be used. Usually, an airtight container is used the container must be kept closed during the drying process. After 4-14 days, depending on the thickness of the flower, the flower will be dry.

e) Glycerine drying:

In this method moisture in a flower or foliage is replaced with glycerine and water. The flower is preserved and not dried. They last indefinitely and can be dusted or even wiped with a damp cloth without risk owing to the leathery texture of leaves. Glycerine drying involves the following process. The bark of the stem is removed and the cut end is smashed using a hammer. This portion of the stem is immersed in the glycerine and water solution. The leaf turns brown with glossy appearance after a month.

f) Microwave oven drying:

Microwave drying is quick and relatively simple. It takes only a few minutes and provides dried flowers that look fresher and more colourful than obtained by other methods. Flowers with thick petals are not suitable for drying in microwave. Since flowers vary in moisture content, texture and density, care should be taken to use the same sized flowers from one species at a time. Suitable flowers such as lilies, roses, violets, zinnias, and dahlias work well with this process.

g) Freeze drying:

Freeze drying also known as lyophilization. It is the process of lowering the temperature of an object and then using a vacuum to extract all the moisture from the item. Freeze dried flowers go through a process in which water is removed as vapor directly from ice, without passing through the liquid state. All other drying methods use evaporation. In other words, water is removed as vapor from liquid water with heated air. This slow preservation process allows the freeze-dried flowers to retain their original form, while the colours become enriched.

h) Skeleton Leaves:

Skeleton leaves are semi-transparent leaves, also called fossil leaves. They are prepared by soaking the fresh leaves in bleached water and then by hand rubbing the soft green flesh from the network of veins. The leaves can be then dyed to variant colours to give them a beautiful and pleasing appearance. These delicate, gorgeous skeleton leaves are a perfect accent for all craft projects. They make a beautiful and elegant statement when they adorn your wedding invitations. They work surprisingly well on gift tags, greeting cards, scrapbooks, collages, papermaking, stencilling, and stamping. They are perfect for decorating bridal bouquet, wedding reception table, candles, and wedding favors.

The dry flower industry driven by increasing consumer demand for its sustainability and long-lasting nature. Further they offer versatility, cost-effectiveness and also aesthetic appeal. The future of this timeless craft appears to be as a vibrant and sustainable industry.

Leveraging Cybrids for Enhanced Vegetable Crop Breeding



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Abstract

Cybrids, or cytoplasmic hybrids, represent a novel frontier in plant breeding that harnesses the power of both nuclear and cytoplasmic genomes. By merging the nucleus of one species with the cytoplasm of another through protoplast fusion, breeders can introduce traits otherwise inaccessible through conventional methods. This unique approach has opened new avenues for developing cytoplasmic male sterility (CMS) lines, enhancing disease resistance, improving stress tolerance, and augmenting photosynthetic efficiency in vegetable crops. Applications in crops like tomato, capsicum, and brassicas demonstrate the potential of cybrids to overcome hybridization barriers, accelerate trait introgression, and reduce reliance on chemical inputs. Despite challenges in regeneration efficiency and nuclear–cytoplasmic compatibility, cybrids remain a promising tool in future-ready breeding strategies, particularly when integrated with cutting-edge technologies like CRISPR-based cytoplasmic engineering. By bridging traditional breeding and modern biotechnology, cybrids hold immense potential for achieving sustainable productivity and climate-resilient vegetable crops.

Keywords: Cybrids, cytoplasmic hybrids, protoplast fusion, cytoplasmic male sterility (CMS), vegetable improvement, cytoplasmic inheritance, disease resistance.

Introduction

Global agriculture faces the dual challenge of ensuring food and nutritional security while adapting to rapidly changing climatic conditions. Vegetable crops, being vital sources of vitamins, minerals, and antioxidants, require innovative breeding approaches to enhance yield, resilience, and sustainability. Traditional breeding strategies often encounter limitations such as sexual incompatibility, narrow genetic bases, and linkage drag, restricting the introgression of desirable traits from wild relatives.

Cybrids, or cytoplasmic hybrids, have emerged as a transformative solution in this context. They are produced by fusing the nucleus of one plant with the cytoplasmic components viz. mitochondria and plastids of another, thereby combining nuclear and cytoplasmic diversity within a single genotype (Bacman *et al.*, 2020). This novel system provides breeders with an opportunity to exploit cytoplasmic inheritance for targeted improvements. The development of cytoplasmic male sterility (CMS) lines for hybrid seed production, introduction of cytoplasmic disease resistance, and transfer of stress-tolerant organelles are notable achievements demonstrating the versatility of cybrids in vegetable crop improvement.

With advances in protoplast fusion, molecular markers, cytological confirmation, and tissue culture techniques, cybridization has moved from a conceptual novelty to a practical breeding tool. As climate resilience and resource-efficient agriculture become urgent priorities, cybrids stand at the intersection of classical breeding and modern biotechnology, offering unique prospects for revolutionizing vegetable improvement.

What are Cybrids?

Cybrids are plants that contain a hybrid combination of the nuclear genome of one species and the cytoplasmic genome (mitochondria or plastids) of another species.

- **Nuclear genome:** This is the regular genetic material found in the plant's cell nucleus (DNA).
- **Cytoplasmic genome:** This refers to the DNA found in the mitochondria and plastids (e.g., chloroplasts). Cytoplasmic inheritance is generally maternally inherited.

Cybrids are typically created through the fusion of two protoplasts (the cell walls of plant cells are removed to expose the cytoplasm and the nucleus). One protoplast comes from the plant providing the nuclear genome, and the other comes from the plant contributing the cytoplasm.

Features of cybrids

- **Cytoplasmic inheritance:** The key feature of cybrids is their cytoplasmic inheritance. Unlike nuclear DNA (which follows Mendelian inheritance), cytoplasmic DNA is passed down only maternally. This means that the cytoplasmic traits are inherited only from the maternal parent (the plant providing the cytoplasm).
- **Cytoplasmic diversity:** Cybrids provide a mechanism to introduce new cytoplasmic diversity into a crop species, which is beneficial in cases where the nuclear genome alone doesn't exhibit the desired traits.

Advantages of cybrids

1. **Breaking hybrid barriers:** Cybrids enable the creation of hybrids between species that would normally be incompatible due to cytoplasmic incompatibility, such as crossing species from different genera.
2. **Novel genetic variation:** They introduce novel genetic variation without compromising the desired nuclear traits of the crop. This can enhance traits such as disease resistance, stress tolerance, and productivity.
3. **Faster crop improvement:** Traditional breeding can take decades, but cybrids enable faster introgression of beneficial traits.
4. **Reduced need for pesticides and fertilizers:** Traits like disease resistance and stress tolerance can lead to reduced pesticide use, improving sustainability.

Processes involved in hybrid formation

Cybrids are produced through a process called **protoplast fusion** (Galun and Aviv, 1991), which involves several key steps (Fig. 1):

1. Protoplast isolation:

- Protoplasts are plant cells that have had their cell wall removed, leaving behind the plasma membrane, cytoplasm, and organelles (mitochondria, plastids, etc.).
- This is typically achieved by enzymatic digestion of the cell walls.
- The protoplast isolation can be any of the following ways (Eriksson, 2018).

a) Mechanical method (Historical)

- **Process:** Plasmolyze tissue (e.g., with sucrose) and physically cut the cells. The protoplasts shrink away from the wall and are released upon cutting.
- **Pros:** Simple, no enzymatic concerns.
- **Cons:** **Low yield**, only suitable for highly vacuolated cells (e.g., onion bulb scale), high damage rate. **Rarely used today.**

b) Enzymatic method (Standard)

- **Process:** Incubate tissue in a cocktail of cell wall-degrading enzymes.
 - ✓ **Macerozyme/Pectinase:** Degrades pectin (middle lamella) to separate cells.
 - ✓ **Cellulase/Hemicellulase:** Degrades cellulose (primary/secondary cell wall) to release protoplasts.
- **Pros:** High yield of viable protoplasts, gentle on cells, suitable for a wide range of tissues.

c) Sequential vs. Mixed enzymatic method

- **Sequential method:** Two-step process.
 - ✓ **Incubation in Pectinase** to break middle lamella and create individual cells.
 - ✓ **Transfer to Cellulase** to digest the primary wall and release protoplasts.
- **Mixed method:** One-step process using a combined enzyme solution. Faster and more common.

2. Enucleation:

- One of the protoplasts (usually the donor of the cytoplasm) undergoes **enucleation**, which means its nucleus is removed (often via physical, chemical, or irradiation methods) (Fakhrai *et al.*, 1990).

3. Protoplast fusion:

- The enucleated protoplast (cytoplasmic donor) is fused with a protoplast containing a full set of nuclear DNA. This fusion can be induced by:
 - ✓ **Chemical agents** (such as polyethylene glycol - PEG)
 - ✓ **Electrofusion** (applying an electric field to facilitate the fusion)

4. Cybrid regeneration:

- After fusion, the new hybrid cells are allowed to regenerate into full plants through tissue culture techniques. These regenerated plants have the nuclear genome of one plant and the cytoplasmic genome of another.

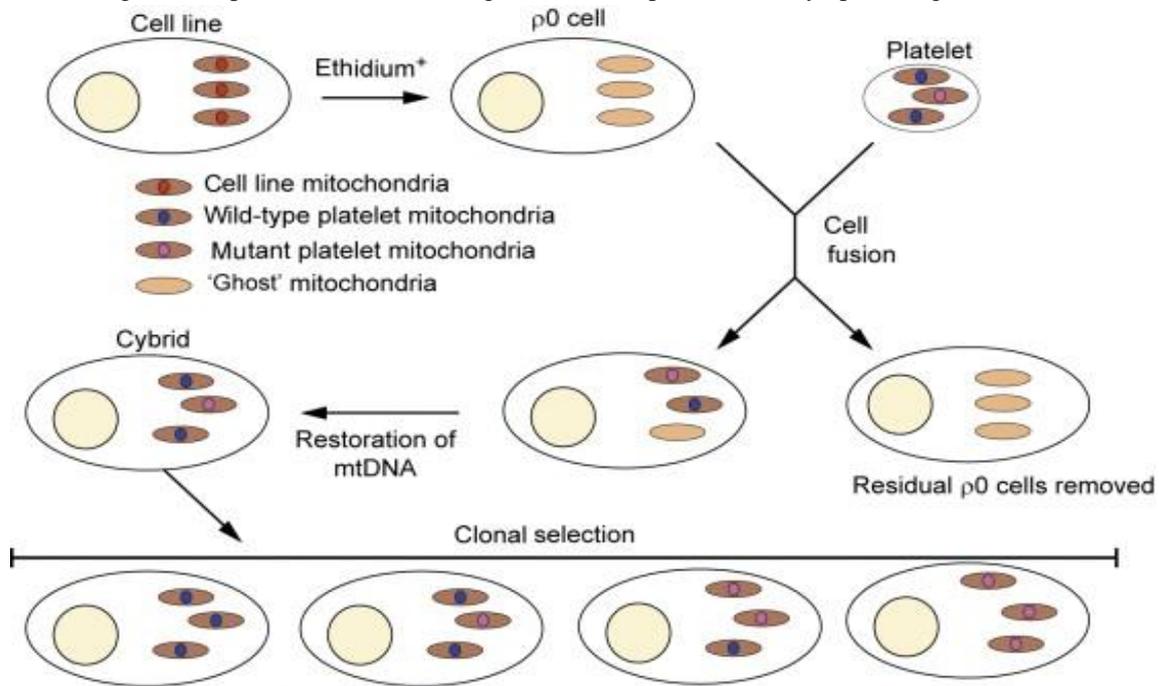


Fig. 1. Overview of Cybridization process (Bahr *et al.*, 2020)

5. Verification of cybrids

The confirmation of cybrids can be done in any one of the following ways (Cai *et al.*, 2009),

- ✓ **Molecular markers**
 - RFLP, PCR, mtDNA/chloroplast DNA specific markers.
- ✓ **Biochemical assays**
 - e.g., isozyme analysis.
- ✓ **Morphological/physiological traits**
 - Traits related to cytoplasm (e.g., cytoplasmic male sterility, chlorophyll mutations).

Morphological marker for identification of MS lines

Morphologically, the presence of male sterility can be detected by following visual characteristics in vegetables (Chaudhari, 2023).

Morphological markers	Vegetables
Potato leaf, Green stem	Tomato
Brown seed coat colour	Onion
Purple stem pigmentation	Cabbage
Bright green hypocotyls	Broccoli
Glabrous seedling	Muskmelon
Non-lobed leaf, glabrous seedling	Watermelon
Glossy foliage	Brussels sprout

Cytological confirmation

(a) Fluorescent staining and microscopy

- **DAPI/Hoechst staining:** stains nuclear DNA, confirming presence/absence of nuclei from both parents.
- **Rhodamine-123 / MitoTracker dyes:** specifically highlight mitochondria to confirm organelle inheritance.
- **Chlorophyll autofluorescence:** checks for the origin and stability of chloroplasts.

(b) Flow cytometry

- Determines **DNA content and ploidy level** of regenerated cybrids.

- Confirms whether the nuclear genome is haploid, diploid, or polyploid (important for distinguishing cybrids from somatic hybrids).
- Coupled with fluorescent dyes (propidium iodide, SYBR Green) to measure nuclear DNA accurately.

(c) Chromosome analysis

- Karyotyping ensures that the nucleus belongs to only one parent.
- Excludes complete somatic hybrids, which show combined chromosome sets.

Applications of cybrids in vegetable crop improvement

Cybrids hold significant potential for improving vegetable crops in several ways (Shuro, 2018):

1. Male sterility (CMS) and hybrid seed production:

- **Cytoplasmic male sterility (CMS)** is a critical trait for hybrid seed production.
- By using cybrids, researchers can create CMS lines that do not produce functional pollen but can still produce seeds. This helps in the production of hybrid seeds, which often exhibit heterosis (hybrid vigor), leading to higher yields, better resistance to diseases, and improved stress tolerance.
- **Example:** In Brassica, CMS lines have been developed for hybrid seed production.

2. Cytoplasmic disease resistance:

- Cytoplasmic genomes often contain disease resistance traits that are absent in the nuclear genome. By introducing a beneficial cytoplasm into a crop, resistance to specific diseases can be achieved.
- **Example:** The use of cybrids to introduce resistance to the Potato virus Y (PVY) in tomatoes or clubroot resistance in Brassica species.

3. Improvement in stress tolerance:

- The cytoplasm of wild relatives of vegetable crops can provide increased tolerance to stresses such as drought, salinity, or temperature extremes.
- Mitochondria in particular play a crucial role in energy production and stress response mechanisms in plants. By transferring mitochondria with superior stress tolerance traits into crops, researchers can enhance stress resilience.
- **Example:** Drought tolerance in tomatoes or heat resistance in capsicum.

4. Increased photosynthetic efficiency:

- The chloroplasts of wild species are often more efficient at photosynthesis due to their adaptation to harsh environments.
- By integrating chloroplasts from wild relatives into cultivated vegetables, cybrids can lead to enhanced photosynthetic efficiency and overall productivity.
- **Example:** Tomato plants with improved chloroplasts from wild relatives.

5. Introgression of beneficial traits:

- Cybrids allow for the introgression of beneficial traits from wild species or distant relatives into a crop species without fully crossing them. This helps avoid linkage drag, where unwanted traits from the wild species are inherited along with the desired traits.
- **Example:** Pepper or onion cybrids that introduce traits like resistance to pathogens or improved fruit quality.

Limitations and Challenges of Cybrids

1. **Regeneration issues:** Not all fused protoplasts can regenerate into whole plants, making the process technically challenging.
2. **Complexity in selection:** Identifying and selecting plants with the desired nuclear-cytoplasmic combinations can be difficult and time-consuming.
3. **Incompatibility:** Cybrids may exhibit reduced vigor or incompatibility if the nuclear and cytoplasmic genomes are not well-matched.
4. **Regulatory and public perception:** Cybrids are still relatively new, and there may be regulatory hurdles and concerns regarding the use of **cytoplasmic material from wild relatives**.

Future prospects of cybrids in vegetable crop improvement

- **Crispr-Cas9 and gene editing:** The use of gene editing technologies combined with cybrids holds exciting potential for targeted improvements in cytoplasmic traits.

- **Climate resilience:** Cybrids could play a significant role in breeding crops that are more resilient to **climate change**, such as drought-resistant or heat-tolerant varieties.
- **Cytoplasmic engineering:** The future may also involve more advanced methods of cytoplasmic engineering, where scientists can design the ideal cytoplasm for a specific trait, like enhancing photosynthetic efficiency or resistance to environmental stress.

Conclusion

Cybrids represent a powerful tool in vegetable crop improvement. By exploiting the potential of cytoplasmic inheritance, breeders can introduce novel traits like disease resistance, stress tolerance, and male sterility for hybrid seed production. While challenges remain in their widespread use, ongoing research into cybrids holds promise for more sustainable and productive vegetable crops in the future.

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Fruits and Vegetables: The Scientific Key to Better Nutrition



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When it comes to healthy living, fruits and vegetables are not just colorful additions to our plate — they are nature’s most powerful gift to human health. Science consistently proves that eating a wide variety of fruits and vegetables is the simplest, most effective way to improve nutrition and prevent disease.

Nutrient Powerhouse

Fruits and vegetables are rich sources of essential vitamins (like vitamin C, A, and folate), minerals (potassium, calcium, magnesium), and dietary fiber. These nutrients work together to boost immunity, improve digestion, and maintain energy levels throughout the day. The natural antioxidants present in them — such as carotenoids, flavonoids, and polyphenols — protect our cells from damage, reducing the risk of chronic diseases.

Disease Prevention Through Science

Research shows that people who consume at least five servings of fruits and vegetables per day have a significantly lower risk of heart disease, stroke, and certain cancers. Fiber-rich vegetables help regulate blood sugar levels and support a healthy gut microbiome, while fruits provide natural hydration and a quick source of energy without harmful fats or cholesterol.

Eat the Rainbow

A diverse diet (i.e. “eating the rainbow”) enhances micronutrient intake and supports overall health and disease prevention. Each colour group of fruits and vegetables brings a unique set of health benefits.

- **Red (Tomatoes, Watermelon):** Rich in lycopene, good for heart health.
- **Orange/Yellow (Carrots, Mangoes):** Packed with beta-carotene, good for eyes and skin.
- **Green (Spinach, Broccoli):** Loaded with iron, calcium, and detoxifying compounds.
- **Purple/Blue (Brinjal, Berries):** High in anthocyanins, good for brain function.
- **White (Garlic, Cauliflower):** Support immunity and reduce inflammation.

Key Nutrients and Health Benefits

Fruit	Key Nutrients	Main Health Benefit
Apple	Dietary fiber, Vitamin C	Improves digestion, boosts immunity
Banana	Potassium, Vitamin B6	Supports heart health, regulates blood pressure
Mango	Vitamin A, Vitamin C	Good for eye health, strengthens immunity
Guava	Vitamin C (very high), Fiber	Enhances immunity, supports digestion
Papaya	Vitamin C, Papain enzyme	Aids digestion, promotes glowing skin
Watermelon	Lycopene, Water (92%)	Hydration, heart health
Vegetable	Key Nutrients	Main Health Benefit
Spinach	Iron, Folate, Vitamin K	Builds red blood cells, strengthens bones
Carrot	Beta-carotene (Vitamin A)	Improves eyesight, skin health
Tomato	Lycopene, Vitamin C	Powerful antioxidant, reduces cancer risk
Broccoli	Vitamin C, Calcium, Fiber	Boosts immunity, supports bone health
Beetroot	Nitrates, Folate	Improves blood flow, lowers blood pressure
Cauliflower	Vitamin C, Choline	Good for brain health, detoxification

Daily Nutrient Requirements (for an Average Healthy Adult)

Nutrient	Recommended Daily Intake	Function
Carbohydrates	275–325 g/day (45–65% of total calories)	Main source of energy
Protein	0.8–1.0 g per kg body weight (≈ 50–60 g/day for adults)	Muscle building, repair, enzymes
Fat	50–60 g/day (≈ 20–30% of total calories)	Energy storage, hormone production, absorption of fat-soluble vitamins
Vitamin A	600 µg/day (men), 500 µg/day (women)	Good vision, healthy skin
Vitamin C	40 mg/day	Immunity, wound healing, antioxidant
Vitamin D	600 IU/day (≈ 15 µg)	Bone health, calcium absorption
Vitamin E	8–10 mg/day	Antioxidant, protects cells
Vitamin K	55–65 µg/day	Blood clotting, bone health
B-Complex (B1, B2, B3, B6, B12, Folate)	Requirements vary (B12 ≈ 2.4 µg/day, Folate ≈ 400 µg/day)	Energy metabolism, nerve function, red blood cell formation

The below table depicts the daily Requirement (Average Adult) and Fruits & Vegetables Contribution. Eating five or more servings per day lowers risk of heart disease and stroke by approximately 20%.

Daily Requirement (Average Adult) and Fruits & Vegetables Contribution

Nutrient	Daily Requirement (Average Adult)	Fruits & Vegetables Contribution
Carbohydrates	275–325 g/day	Fruits like banana, mango, and vegetables like potato, sweet potato give natural sugars & starch (low GI in most veggies).
Protein	50–60 g/day	Vegetables like peas, beans, spinach, broccoli provide small amounts (2–5 g per serving) — need pulses/grains to meet full requirement.
Fat	50–60 g/day	Fruits & vegetables are naturally low in fat — avocado, olives, and nuts (technically fruits) contribute healthy fats.
Vitamin A	500–600 µg/day	Carrot, pumpkin, spinach, mango, papaya are rich sources of beta-carotene (precursor of Vitamin A).
Vitamin C	40 mg/day	Guava (200 mg/100g), amla (600 mg/100g), citrus fruits, tomato — easily meet daily need.
Vitamin D	600 IU/day	Very little in fruits/veggies (need sunlight or fortified foods).
Vitamin E	8–10 mg/day	Spinach, broccoli, and some fruits like avocado contribute moderate amounts.
Vitamin K	55–65 µg/day	Dark leafy vegetables (spinach, kale, broccoli) are excellent sources.
Folate (B9)	400 µg/day	Spinach, asparagus, citrus fruits, and legumes provide good amounts.
Minerals (K, Ca, Mg)	Potassium ~3500 mg/day, Calcium ~1000 mg/day	Banana, orange, leafy greens are rich in potassium & calcium.

Fruits and vegetables are nutrient-dense, delivering essential vitamins, minerals, fiber, and antioxidants that contribute to lower risks of chronic diseases. Daily intake recommendations range between 400–500 g to gain substantial health benefits (WHO).

Routine Food and Fruit & Veg Substitution

Routine Food	Healthier Fruit/Vegetable Substitute	Benefit
Deep-fried snacks (samosa, chips)	Fresh cut vegetables with hummus / sprouts salad	Cuts excess oil & fat, adds fiber + vitamins
White rice for one meal	Vegetable-rich millet upma, vegetable quinoa bowl, or sweet potato mash	Lower glycemic index, more fiber & micronutrients
Sugary sweets/desserts	Fresh fruits (banana, papaya, apple) or fruit salad with curd	Natural sugars + vitamins, no refined sugar
Creamy curries with excess oil	Lightly sautéed vegetables with spices / vegetable stew	Retains nutrients, less fat
Evening tea with biscuits	Vegetable soup or fruit smoothie	Adds antioxidants, keeps you fuller
Carbonated drinks	Fresh fruit juice (no added sugar) / coconut water	Replaces empty calories with electrolytes and vitamins
Refined flour snacks	Steamed vegetable momos / whole-grain veggie wraps	More fiber, slower sugar release

Price Aspect of Fruits & Vegetables

- **Seasonal Price Variation:**
 - Prices of fruits & vegetables fluctuate based on season (e.g., mangoes are cheaper in summer, tomatoes may become costly during off-season).
 - Buying **seasonal produce** is cheaper and nutritionally better.
- **Compared to Processed Foods:**
 - Fruits & vegetables are often cheaper than packaged snacks, chips, or fast food (especially when bought locally from markets).
 - Example: A plate of cut watermelon may cost less than a packet of chips and is much healthier.
- **Storage & Waste Cost:**
 - Vegetables are perishable, so careful buying and storage is important to avoid spoilage and extra expense.
 - Frozen or dried options can be slightly more expensive but last longer.
- **Economic Benefit:**
 - Substituting part of your diet with fruits & vegetables can reduce long-term healthcare costs by preventing lifestyle diseases like obesity, diabetes, and hypertension.

Cost Comparison: Junk Food vs. Fruits & Vegetables (Approx. prices — per 100 calories)

Food Item	Price (₹)	Calories (per serving)	Cost per 100 Calories	Nutrition Quality
Potato Chips (25 g)	20	~130	₹15	High fat, low vitamins
Soft Drink (300 ml)	20	~120	₹16	Empty calories, no nutrition
Chocolate Bar (40 g)	40	~210	₹19	High sugar, low nutrients
Banana (1 medium)	6	~100	₹6	Good carbs, potassium, fiber
Papaya (150 g)	10	~60	₹17	Vitamin C, fiber, low fat
Tomato (200 g)	8	~35	₹23	Vitamin C, antioxidants
Cooked Spinach (1 cup)	15	~40	₹38	Iron, vitamin A, folate

COST COMPARISON

JUNK FOOD vs. FRUITS & VEGETABLES

JUNK FOOD	FRUITS & VEGETABLES
 ₹ 20	 Banana 1 medium ₹ 6
Potato Chips 25 g ₹ 15	 Papaya 150 g ₹ 10
 ₹ 20	 Tomato 200 g ₹ 23
Soft Drink 300 ml ₹ 16	 Cooked Spinach 1 cup ₹ 15
 ₹ 40	
Chocolate Bar 40 g ₹ 19	

COST PER 100 CALORIES

Including more fruits and vegetables in our daily meals is one of the simplest and most affordable ways to improve health. They are rich in essential vitamins, minerals, and fiber, while being naturally low in fat and calories. Replacing calorie-dense junk food and sugary snacks with seasonal fruits and vegetable-based dishes can reduce long-term health risks and cut unnecessary costs. Choosing local, fresh produce ensures better nutrition and supports farmers. A colorful plate of fruits and vegetables is the easiest, most affordable way to stay healthy. They give vitamins, minerals, and fiber, while cutting junk calories — keeping you fit, energetic, and disease-free.

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Carbon Footprint of Vegetable Production Systems: A Comparative Analysis of Open-Field vs. Protected Cultivation



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Abstract:

The growing demand for vegetables to meet nutritional security has intensified concerns about the environmental sustainability of production systems. Agriculture contributes nearly 19–20% of global greenhouse gas (GHG) emissions, of which vegetable cultivation accounts for a significant portion through fertilizer application, irrigation, pesticide use and energy-intensive operations. Carbon footprint analysis provides a scientific method to quantify emissions associated with food production and identify strategies for mitigation. This article compares the carbon footprint of open-field vegetable production and protected cultivation systems such as polyhouses, greenhouses and net houses. While open-field systems are less energy-intensive, they are characterized by lower yields, higher postharvest losses and inefficient input use. Protected cultivation ensures higher productivity and input efficiency but carries additional embodied emissions due to construction materials, plastic waste and electricity use for microclimate management. The article discusses emission profiles, advantages and limitations of both systems and provides strategies for developing low-carbon vegetable production models. The findings suggest that integrating renewable energy, biofertilizers, nano-fertilizers and improved postharvest handling in protected cultivation can lead to a sustainable balance between productivity and environmental stewardship.

Keywords: Carbon footprint, greenhouse gas emissions, open-field vegetables, protected cultivation, sustainability, climate-smart horticulture

Introduction:

Vegetables are essential components of a balanced diet, providing vitamins, minerals, fiber and bioactive compounds crucial for human health. India is the second-largest producer of vegetables globally with an annual production of about 215 million tonnes (2023–24) from 11 million hectares. However, increasing population pressure and changing dietary preferences have escalated vegetable demand, pushing farmers to intensify production (FAO, 2024).

While vegetable production ensures food and nutritional security, it is also resource-intensive and contributes significantly to greenhouse gas (GHG) emissions. Global estimates indicate that agriculture is responsible for around 5.5–6.0 Gt CO₂-equivalent annually, of which horticulture contributes nearly 10–12% (IPCC, 2023). The major sources of emissions in vegetable systems include nitrogen fertilizers (N₂O release), irrigation energy, pesticide production, soil management and post-harvest losses.

In India, the adoption of protected cultivation (polyhouses, net houses and greenhouses) is expanding rapidly, covering nearly 70,000 hectares in 2023. These systems are promoted for their ability to produce high-value vegetables such as capsicum, tomato, cucumber and leafy greens with enhanced quality and reduced input losses. However, the energy use in protected systems for cooling, heating and irrigation introduces new challenges in terms of carbon emissions.

This article compares the carbon footprint of open-field and protected cultivation systems for vegetable production, highlighting emission profiles, challenges and strategies for building climate-smart horticulture in India.

Carbon Footprint in Vegetable Production Systems:

The **carbon footprint (CF)** is defined as the total amount of greenhouse gases emitted directly or indirectly during the life cycle of a product, expressed in CO₂-equivalent. In vegetable cultivation, carbon footprint arises from:

- **Fertilizers and chemicals:** Production, transport and application of urea, DAP and pesticides.
- **Soil emissions:** Release of nitrous oxide (N₂O) from nitrogen fertilizers.

- **Energy use:** Diesel or electricity for irrigation, tillage, pumping and protected structures.
- **Postharvest losses:** Wastage during harvesting, storage and transport leading to embedded emissions.

Understanding the carbon footprint is crucial for identifying hotspots and adopting mitigation strategies tailored to vegetable systems.

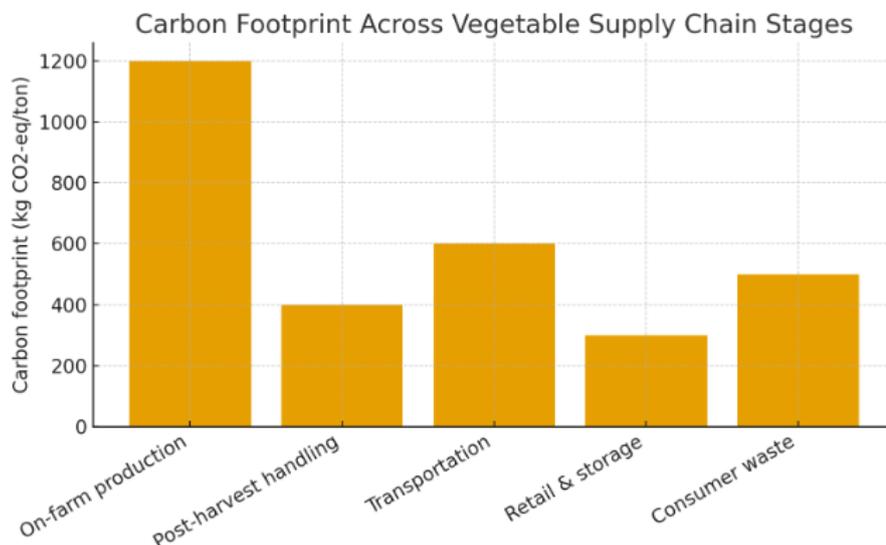


Fig. No. 1 - Carbon Footprint Across Vegetable Supply Chain Stages
(kg CO₂-eq per ton of produce)

Open-Field Vegetable Cultivation: Emission Profile:

Open-field cultivation is the traditional method of vegetable farming in India, characterized by direct exposure to climatic conditions and reliance on natural resources. Its carbon footprint is shaped by the following factors:

- **High dependence on synthetic fertilizers:** Open-field crops receive large doses of urea, DAP and potash, leading to higher N₂O emissions. Studies show that nitrogen fertilizers account for **60–70% of total emissions** in open-field vegetables (Patra *et al.*, 2022).
- **Tillage operations and fuel use:** Frequent ploughing, inter-cultivation and weeding require diesel-based machinery, adding CO₂ emissions.
- **Irrigation energy demand:** Shallow tube wells and pump sets consume significant electricity or diesel, particularly in crops like tomato and onion.
- **Postharvest losses:** About **20–25% of vegetables in India are lost postharvest**, adding to hidden emissions since embedded resources are wasted (ICAR, 2023).
- **Lower productivity per unit area:** On average, open-field vegetables yield less than protected cultivation, meaning higher carbon intensity per kilogram of produce.

Thus, although open-field systems involve fewer infrastructural emissions, their inefficiencies in fertilizer use and high losses raise their per-unit carbon footprint.

Protected Cultivation: Energy and Carbon Considerations

Protected cultivation systems—such as polyhouses, net houses and greenhouses—are increasingly promoted for high-value vegetables. Their carbon footprint arises from both **construction-related embodied emissions** and **operational energy use**:

- **Higher input efficiency:** Fertilizer and water use is more precise, reducing N₂O emissions. Studies in capsicum and cucumber show input efficiency increases by **25–40%** compared to open-field systems (Sharma *et al.*, 2021).
- **Increased productivity:** Protected structures yield **2–5 times more vegetables** than open fields, lowering the carbon footprint per kilogram of produce.
- **Energy consumption:** Cooling, heating and lighting require electricity, leading to indirect emissions. Use of diesel generators in remote areas further adds to the footprint.

- **Material use and embodied carbon:** Polyethylene films, steel frames and concrete contribute to carbon emissions during construction. Their disposal, especially plastic waste, is a growing environmental concern.
- **Reduced postharvest losses:** Better quality produce with extended shelf life reduces wastage, indirectly lowering embedded emissions.

Overall, protected cultivation offers lower carbon intensity per unit of produce but requires careful management of energy and material use.

Comparative Analysis: Open-Field vs. Protected Systems

A comparison of the two systems reveals:

- **Productivity:** Protected systems produce 3–5 kg of tomato per plant, while open-field yields remain at 1–2 kg per plant.
- **Carbon footprint per kg:** Studies indicate that the carbon footprint of capsicum in open-field systems is about 3.0–3.5 kg CO₂-eq/kg, while in protected cultivation it reduces to 1.2–1.5 kg CO₂-eq/kg (FAO, 2023).
- **Resource use:** Fertilizer and water efficiency in protected systems can be up to 40% higher than open-field.
- **Trade-off:** While protected systems carry upfront emissions from construction and energy use, they compensate by delivering higher yields and reduced wastage.

Thus, protected cultivation proves more carbon-efficient in the long run, particularly when integrated with renewable energy sources.

Vegetable	Carbon Footprint
Tomato (greenhouse)	2.9
Tomato (open field)	1.4
Potato	0.4
Cabbage	0.3
Onion	0.5

Table No. 1 - Carbon Footprint of Selected Vegetables (kg CO₂-eq/kg produce)

Strategies for Low-Carbon Vegetable Production:

1. **Adoption of renewable energy:** Use of solar-powered pumps, biogas-based heating and LED lighting can reduce electricity-related emissions.
2. **Low-carbon inputs:** Incorporating biofertilizers, nano-fertilizers and composts reduce reliance on energy-intensive synthetic fertilizers.
3. **Efficient irrigation:** Drip and fertigation systems in both open and protected farming minimize water and energy use.
4. **Plastic recycling and biodegradable alternatives:** To address the problem of plastic waste in protected cultivation.
5. **Improved postharvest management:** Zero-energy cool chambers, solar dryers and better storage infrastructure can cut losses and associated emissions.
6. **Life cycle assessment (LCA):** Routine evaluation of emissions throughout the crop cycle to identify hotspots and improve practices.

Challenges:

- **High initial cost:** Protected cultivation requires substantial investment in structures, making it unaffordable for smallholders.
- **Energy dependence:** Reliance on grid electricity or diesel for protected systems increases operational emissions.
- **Plastic waste management:** Polyethylene sheets have a short lifespan (2–3 years), creating disposal issues.

- **Knowledge and skill gaps:** Farmers often lack awareness of carbon footprint metrics and mitigation practices.
- **Policy and incentives:** There is a need for carbon credit schemes and subsidies to promote low-carbon horticulture.

Future Thrusts:

The path ahead involves integrating renewable energy, promoting low-carbon inputs, strengthening research on carbon accounting and enabling farmer access to carbon markets. Partnerships between research institutes, government and private firms can accelerate adoption of sustainable protected farming in India.

Conclusion

Vegetable cultivation, whether in open-field or protected systems, contributes significantly to carbon emissions, but the intensity varies across production models. Open-field systems are less energy-intensive initially but face challenges of inefficiency, high fertilizer emissions and postharvest losses. Protected cultivation, on the other hand, delivers superior productivity and reduced per-unit emissions, though at the cost of higher infrastructure-related carbon footprint and energy dependence. The future of sustainable vegetable production lies in “**carbon-smart protected cultivation**”—integrating renewable energy, eco-friendly inputs, plastic recycling and efficient irrigation. With the right policy support, India can transition towards a low-carbon horticulture sector, ensuring food security while meeting climate commitments.

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Flag Leaf- The Most Important Part of A Rice Plant



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Abstract

The flag leaf contributes 45% of rice grain yield because it mostly provides photosynthetic products to the panicle, so a significant improvement in grain output is directly related to improving flag leaf features. A field test was conducted to investigate the relationship between paddy grain yield and the top three leaves. The third leaf is longer than the first and second leaves among the top three leaves. The first leaf is wider than the second and third leaves. The angle of the third leaf is more compared to the top two leaves.

Keywords: flag leaf, photosynthesis, grain yield

Introduction

Rice (*Oryza sativa* L) is a member of the *Oryza* genus in the Gramineae family and is a staple meal for over half of the world's population. High yield has become a main goal in rice breeding programmes as the world's population grows. The main source of carbohydrate production is flag leaf and its penultimate leaves (Al-Tahir, 2014). Photosynthesis in this leaf provides the majority of the carbohydrates needed for grain filling so it is the most important leaf for yield potential. Flag leaf contributes 45% of rice grain yield because it mostly provides photosynthetic products to the panicle. Plant breeding may result in a significant improvement in grain output by improving flag leaf features. The length of the flag leaf has long been considered as one of the most important variables in the development of novel rice plant ideotypes with high yielding potential (Vangahun, 2012). Leaf length varies greatly in rice and is closely related to leaf angle. Droopyness is related with long leaves, whereas erectness is associated with short and tiny leaves (Vangahun, 2012).



Flag leaf is important

1. Major source of photosynthates

The primary source of energy for photosynthesis in the flag leaf is sunlight, which provides the necessary energy for the process. The flag leaf is crucial for a plant's reproductive stage because it produces the majority of the carbohydrate's (Assimilates) needed for grain filling in crops like rice and wheat. This is due to its ideal position at the top of the canopy, maximizing light interception.

- a. **Light Energy:** Sunlight is absorbed by chlorophyll, the green pigment found in the flag leaf's chloroplasts, to power the photosynthetic process.
- b. **Carbon Dioxide:** Atmospheric CO₂ enters the leaf through tiny openings called stomata.
- c. **Water:** Water is absorbed from the soil and transported to the leaves.
- d. **Carbohydrate Production:** These raw materials are used to create carbohydrates, which are essential for grain development.

2. High photosynthetic rate

A flag leaf has a high photosynthetic rate because its location at the top of the plant allows for greater light interception, which is a primary driver of photosynthesis. This high rate of photosynthesis produces a significant portion of the photosynthetic (sugars) needed to fill the grain in cereals like wheat and rice, making it crucial for yield. The flag leaf's high photosynthetic activity contributes to the plant's overall productivity, especially during the critical stages of flowering and seed maturity.

- a. **Optimal Light Exposure:** Its position at the top of the canopy maximizes its exposure to sunlight, a key factor for photosynthesis.
- b. **Proximity to the Sink:** The flag leaf is close to the developing grains, allowing it to more easily supply them with sugars (assimilates) through a phenomenon known as source-sink relationship.
- c. **Functional Importance:** In cereal crops, a healthy and active flag leaf can contribute a large percentage of the assimilates used to fill the grains, making it essential for grain yield.

3. Direct link to grain yield

There isn't a single "direct link to grain yield of flag leaf" because this relationship is complex and varies by crop and genetics; instead, many studies show a strong positive correlation between improved flag leaf traits (like size, area, and erect angle) and increased grain yield in rice and wheat.

- a. **Photosynthesis:** The flag leaf is a primary source of photosynthetic products that are directly used for grain filling.
- b. **Source-Sink Relationship:** A larger, more efficient flag leaf provides more assimilates to the developing grain (sink), leading to higher yield.
- c. **Light Interception:** An erect flag leaf angle improves light interception and photosynthesis, particularly in dense stands.
- d. **Nitrogen Remobilization:** The flag leaf also plays a role in the remobilization of nitrogen from vegetative organs to the panicles.

4. Target for Breeding

Breeding targets for the flag leaf focus on enhancing photosynthetic efficiency for higher yield by selecting for desirable flag leaf traits like length, width, area, and chlorophyll content. Research has identified key flag leaf traits that positively correlate with grain yield in crops like rice and wheat, providing genetic markers and genes that can be targeted by breeders to develop improved varieties.

- a. **Increased Flag Leaf Size (Length, Width, and Area):** A larger flag leaf provides more surface area for photosynthesis, which can directly translate to higher grain yield.
- b. **Higher Chlorophyll Content:** The flag leaf is a major source of photosynthetic products, so breeding for increased chlorophyll content (measured by SPAD or CCI) enhances photosynthetic capacity and grain yield.
- c. **Optimized Leaf Angle:** An optimal flag leaf angle can improve light interception, benefiting photosynthetic activity.
- d. **Improved Leaf Thickness:** Thicker flag leaves are often associated with higher chlorophyll content, contributing to better photosynthetic performance and yield.

5. Influences grain weight

The flag leaf's size and orientation (area, length, width, and angle) significantly influence grain weight by affecting the plant's photosynthetic capacity and light interception. A larger flag leaf with high chlorophyll content increases the "source" for grain development, while an erect angle allows for better light capture and can improve photosynthesis, contributing to more photosynthates for grain filling, which ultimately determines grain weight and yield.

- a. **Enhanced Photosynthesis:** A healthy flag leaf with good photosynthetic activity provides the "source" of carbohydrates and nutrients during the grain filling stage, which is critical for building the grain's mass.
- b. **Efficient Light Capture:** The flag leaf's position and angle in the canopy affect how much sunlight is captured. An optimal angle ensures that more light is absorbed, maximizing overall photosynthetic output for the plant.

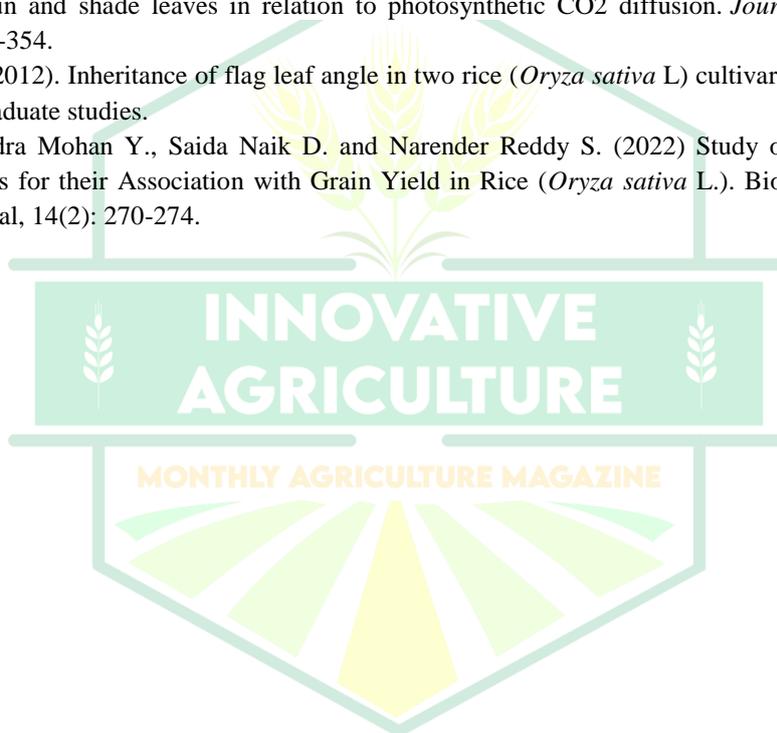
- c. **Genetic Basis:** These flag leaf traits are heritable, meaning they are controlled by specific genes, and breeders can select for these traits to develop high-yielding crop varieties with improved grain weight and yield.

Conclusion

The flag leaf is unequivocally the most important part of a rice plant. Its pivotal role in photosynthesis, grain yield, water and nutrient uptake, and panicle development makes it indispensable for optimal plant growth and productivity. Any damage or stress to the flag leaf can significantly impact crop yields and quality. Therefore, it is essential to prioritize flag leaf health through best management practices to ensure a bountiful harvest. Effective flag leaf management is critical for rice crop success.

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Lawn Establishment and Maintenance



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Lawn is a ground cover of perennial grass, which persists in close mowing and requires proper management practices

Purposes of a lawn

- It is an important element in the garden.
- It leads to unity in garden design.
- It is a natural green carpet and is the carpeted floor of outdoor room.
- It is the heart of the garden and the centre for social life.
- It is the centre piece around which all other garden elements are placed in sub-ordinate order like the royal court, where king occupies the central position and is surrounded by his courtiers.
- It gives restful appearance to the eyes through its green outlook all the time.
- A lush green lawn is refreshing especially during summer.
- Lawn is the best foreground to enjoy the charm and beauty of the ornamental plants and features.
- Prevent soil erosion

Characteristics of a lawn grass

- Look fresh and green throughout the year
- Not patchy
- Cold or drought resistant
- Free from attack of diseases and insects
- Quick growing
- Soft to touch
- Not giving fowl or bad odour.

Types of Grasses Used for Lawns

A. Warm-season (Tropical) Grasses: Best for Indian and tropical climates (grow well in summer, dormant in winter).

1. *Cynodon dactylon* (Doob grass, Bermuda grass)
 - a. Very hardy, drought resistant spreads fast.
 - b. Commonly used in India for durable lawns.
2. *Cynodon transvaalensis* (South African doob grass)
 - a. Finer texture, compact growth, good for ornamental lawns.
3. *Dichanthium annulatum* (Marvel grass)
 - a. Hardy, suitable for dry regions.
4. *Zoysia japonica* (Japanese lawn grass)
 - a. Dense growth, slow-growing, low maintenance.
 - b. Suitable for ornamental and shady lawns.
5. *Paspalum notatum* (Bahia grass)
 - a. Tolerant to poor soils and drought.

B. Cool-season (Temperate) Grasses: Suitable for temperate regions or higher altitudes; remain green in winter, less tolerant to heat.

1. *Lolium perenne* (Perennial ryegrass)
 - Quick germination, good for temporary lawns.

2. *Festuca rubra* (Red fescue)
 - Fine textured shade tolerant.
3. *Agrostis stolonifera* (Creeping bent grass)
 - Fine quality turf, ideal for golf courses.
4. *Poa pratensis* (Kentucky bluegrass)
 - Soft, attractive, widely used in cold climates.

C. Specialty/Ornamental Grasses

1. *Stenotaphrum secundatum* (St. Augustine grass) – coarse, shade tolerant.
2. *Eragrostis curvula* (Weeping love grass) – decorative effect.

Site for planting lawn: South, south-east or south-west open and sunny place for most part of the day with adequate water availability

Method of preparing soil for growing lawn

- Dig soil up to 45 cm depth and expose to sun in May - June.
- Turn soil 2-3 times, remove stones, rocks and break big clods.
- Spread 10-15 cm thick layer of well rotten weed free farm yard manure and thoroughly mix in soil.
- Irrigate the field thoroughly and allow all weeds to germinate.
- Remove all the weeds along with roots manually or spray non-selective type of herbicide like Paraquat or gramaxone @ 1.0-1.5 litre per hectare in about 800- 1000 litre water.

Ideal soil/ growing medium: Sandy-loam, well fertile, drained with good water holding capacity having pH of 5-6 and sufficient humus or organic matter.

Methods of lawn raising

- Seeding
- Dibbling
- Plastering
- Sprinkling
- Turfing
- Artificial lawn making

1. Seeding method

- This method is common to grow cool season lawn grasses.
- About 25 Kg seed is mixed in 200-250 Kg sand or saw dust and is broadcasted evenly in the prepared saw dust and is broadcasted evenly in the prepared field.
- Do light rolling
- Sprinkle water regularly until seedling emerges.
- Less labour is required, but lawn is not even.

2. Dibbling method

- A small bunch of grass along with roots and little stem is taken.
- Planting is done at a spacing of 10 cm apart both row to row and plant to plant. to row and plant to plant.
- Do regular watering until establishment.
- Dibbling is done in June to September.
- Lawn developed by this method is quick, uniform and with more labour and cost.

3. Plastering method

- Grass roots with little stem of 4-5 cm long pieces are mixed with compost and farm yard manure.
- Spread this over prepared field during rainy season.
- Avoid heavy balling.
- Do liberal watering with sprayer

4. Sprinkling method

- Grass roots along with little stem are chopped into small pieces.
- Spread this over prepared field during rainy season.
- Do small raking to mix grass in soil.
- Do small raking to mix grass in soil.

- Do light rolling.
- Do liberal watering with sprayer.
- Do mowing after 70-80 days.

5. Turfing method

- Small pieces of well prepared lawn or turf are cut into square or rectangular shape preferably planted on polythene sheet.
- Fix these in a thoroughly prepared field.
- Fix these in a thoroughly prepared field.
- Do heavy rolling.
- Lawn prepared is clean and weed free.
- Quickest method of lawn raising.

6. Artificial lawn

- Wheat or barley is sown by broadcasting in the well prepared field.
- When the seedlings are about 10 cm height, do light mowing.
- Greenery for short duration can be achieved by sprinkling pine needles in any area.

What is mowing: It is the cutting of lawn grass for maintaining its attractiveness for maximum utility. Lawn mower was invented by Edwin Budding in 1830 in England.

How lawn mowing is affected?

- Mowing stimulates bud development.
- Shoots become thicker and roots shorter.
- Generally lawn height is maintained at 5-7 cm, as very close mowing results in weak growth and mowing at more height may not serve the purpose.
- Mowing at more height may not serve the purpose.
- In one mowing not more than 1/3rd leaves are removed.
- Remove stones or pebbles before mowing, so as to avoid any damage to shears of lawn mower.
- In most of the grasses mowing is done at fortnightly interval.

Purpose of rolling

- Uniformity of growth is achieved by rolling, as it touches the nodes at ground, thereby keeping the area well leveled.
- Heavy rolling is done at the beginning of rainy season
- Heavy rolling is done at the beginning of rainy season followed by light rolling in subsequent months depending upon grass species.

Manures and fertilizers

- Sun hemp is very good green manure before lawn planting.
- In a 30 m² lawn apply 3-5 q well rotten FYM, 10-20 kg lime and 10-20 kg SSP.
- Broadcast a mixture of 50-60g /m² or 1.5 Kg/ 30 m² (2 CAN: 1 SSP: 1 K₂SO₄) twice in February- March and August-September.
- Spray of urea 0.3 per cent is also beneficial.

Aeration

- Occasional spiking or aeration improves root respiration and water infiltration.

Irrigation

- Frequency and amount of irrigation depends upon soil, grass, weather and climate.
- It should be done before wilting or internal water stress.
- Increased watering interval result in deeper root development, thereby decreasing water requirement.
- Watering upto 5-15 cm depth at 8-10 days interval is ideal as frequent light watering is harmful.

Weeding

- Regular mowing checks weed growth by removing upper plant portion and starving of roots.
- For small area hand weeding is done. For controlling broad leaved weeds spray 2,4-D
- For narrow leaved weeds spray Pendimethalin @ 1.5 Kg a.i. per hectare in 1000 litre water.

- In lawn of Korean grass spray benefin or sylvex (0.1%).

Important Lawn Diseases

1. Brown Patch

- **Causal organism:** (*Rhizoctonia solani*)
- **Symptoms:** Circular brown patches (5–50 cm) on turf; leaves rot near soil line; rapid spread in hot, humid weather.
- **Control:** Improve drainage, avoid excess nitrogen, spray Carbendazim / Mancozeb.

2. Dollar Spot

- **Causal organism:** *Sclerotinia homoeocarpa*
- **Symptoms:** Small, round, straw-colored spots (like silver dollars); spots coalesce under moist conditions.
- **Control:** Maintain balanced fertilization, improve aeration, spray Chlorothalonil / Thiophanate-methyl.

3. Pythium Blight (Grease Spot)

- **Causal organism:** *Pythium spp.*
- **Symptoms:** Greasy, dark, water-soaked patches; cottony mycelium during humid nights; turf collapses rapidly.
- **Control:** Ensure good drainage, avoid over-irrigation, apply Metalaxyl fungicide.

4. Fusarium Patch (Snow Mold)

- **Causal organism:** *Fusarium nivale*
- **Symptoms:** Pinkish-white patches (2–10 cm) in cool, moist weather; growth of cottony fungus on leaves.
- **Control:** Proper mowing, avoid heavy thatch, spray Iprodione / Carbendazim.

5. Leaf Spot / Melting Out

- **Causal organism:** *Drechslera / Bipolaris spp.*
- **Symptoms:** Purplish-brown leaf spots that enlarge, leaves wither and die; thinning of lawn.
- **Control:** Avoid water logging, reduce nitrogen and spray Zineb / Mancozeb.

Salient hints for maintaining healthy lawn

- Avoid water standing in rainy season.
- Remove all dead or dry leaves falling during autumn season.
- Do raking in lawn twice once before rains and second
- Do raking in lawn twice once before rains and second after rains.
- Do thinning as and when required

Renovation of old or wild or weedy lawn

- Use notable herbicide to kill all weeds.
- Scrap lawn in rainy season.
- Do raking followed by leveling.
- Do testing of soil and add nutrients and lime as per requirement.
- Plant reliable grass.
- Apply proper manures and fertilizers.
- Broadcast sand, manures as per requirement.
- Maintain optimum moisture.

Innovations in Technology Transfer: Next-Generation Extension Approaches for Sustainable Agriculture



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Abstract

Next-generation extension approaches represent a paradigm shift from the traditional top-down, supply-driven model to a more dynamic, farmer-centric, and context-specific system. These innovative methods leverage digital technologies, pluralistic partnerships, and participatory frameworks to enhance the efficiency, reach, and relevance of technology transfer. This paper explores the limitations of conventional extension and details the characteristics and mechanisms of next-gen approaches, focusing on the role of digital services, multi-stakeholder collaboration, farmer empowerment, and integrated strategies. The goal is to move beyond simply disseminating information to fostering localized, sustainable innovation and improving the overall livelihood of farming communities.

Keywords: Farmer centric, Pluralistic partnerships, multi-stakeholder collaboration, livelihood, sustainable innovation

Introduction

The effectiveness of agricultural extension is crucial for increasing productivity, improving livelihoods, and ensuring food security. However, traditional public extension systems, which typically operate on a linear model of technology transfer, have faced significant challenges, including limited reach, inadequate resources, weak linkages with research, and a one-size-fits-all approach that fails to meet diverse farmer needs. The rapid pace of technological change and evolving market demands necessitate a fundamental transformation of extension services. Next-generation approaches are designed to overcome these constraints by creating a more responsive, integrated, and empowering system. This involves not just transferring technology but also strengthening the entire agricultural innovation system to ensure technologies are relevant, adoptable, and sustainable.

Need of next generation agricultural approaches for effective transfer of technology

The need for next-generation agricultural extension approaches is driven by the limitations of traditional, top-down models in addressing modern-day challenges such as climate change, rising food demand, and resource scarcity. A shift to more dynamic, inclusive, and technology-driven methods is essential to effectively transfer agricultural innovations and build a sustainable and resilient farming sector.

The shortcomings of traditional extension

The conventional "Transfer of Technology" model, which relies on a centralized system to push information from researchers to farmers, has proven ineffective for several key reasons:

- 1. One-size-fits-all approach:** Standardized recommendations fail to account for local variation in climates, soil types, farming scales, and socioeconomic conditions. This leads to inappropriate technology use and limited adoption by diverse farmers.
- 2. Poor reach and limited funding:** Public extension systems often suffer from inadequate funding, a high extension worker-to-farmer ratio, and poor transportation infrastructure. As a result, they fail to reach a large portion of the farming population, especially smallholder and marginalized farmers.
- 3. Weak feedback mechanisms:** The top-down structure provides little opportunity for farmers to give feedback to researchers. This disconnect means that technologies are often developed without considering the real-world needs and constraints of end-users.

4. **Neglect of market linkages:** Traditional extension has historically focused on production, often overlooking crucial factors like market access, consumer demand, and value-chain integration. This results in farmers being unable to capitalize fully on increased productivity.
5. **Slow to adapt:** Public extension agencies can be slow to incorporate and scale up modern agricultural innovations, hindering farmers' ability to keep pace with rapid technological advancements and market changes.

Need of advanced extension approaches for next generation

The need for more advanced and adaptive extension approaches arises from a combination of global pressures and emerging technological opportunities. To address complex global challenges

- A. **Increasing food demand:** With the world population projected to exceed 9 billion by 2050, agricultural production needs to increase significantly. Next-generation extension can facilitate the adoption of efficient and resource-saving technologies required to meet this demand.
- B. **Mitigating climate change:** Climate change is increasing the frequency of droughts, floods, and extreme weather events, which threaten crop stability and food security. Next-generation approaches can accelerate the adoption of climate-resilient crops, conservation agriculture, and smart management practices that build resilience.
- C. **Promoting sustainability:** Excessive use of chemical inputs and poor farming practices have led to soil degradation and water contamination. Next-gen extension is needed to promote sustainable practices that conserve natural resources and minimize environmental damage.
- D. **Maximizing resource efficiency:** With pressures on natural resources like land and water, next-generation extension leverages precision agriculture and digital tools to help farmers optimize their inputs and minimize waste.
- E. **Digital revolution:** The widespread availability of mobile phones, the internet, and data analytics offers an unprecedented opportunity to deliver timely, accurate, and personalized information to farmers at scale. Digital extension can overcome geographical barriers and bypass traditional bottlenecks.
- F. **Precision and intelligence:** The integration of AI, machine learning, and remote sensing allows for advanced farm management. Extension must evolve to help farmers interpret complex data and translate it into actionable strategies for higher productivity and profitability.
- G. **Data-driven decision making:** Modern extension enables data collection and analysis to support evidence-based decisions, allowing farmers to predict yields, manage risks, and optimize resource allocation more effectively. To foster farmer empowerment and market linkages
- H. **Demand-driven services:** Next-gen approaches are farmer-centric and participatory, giving farmers a voice in what technologies and information are needed. This increases the relevance of innovations and boosts adoption rates.
- I. **Strengthened value chains:** By integrating with market intelligence, next-gen extension can help farmers understand market demands and produce higher-value crops, securing better prices and improving their economic stability.
- J. **Inclusivity:** Next-gen extension can target marginalized groups, such as women and youth, who are often overlooked by traditional systems. By using innovative platforms, it can tailor services to address their specific needs.

Different methods of next-generation extension

1. Digital extension services

The proliferation of digital technology, especially mobile phones, has enabled the development of scalable and targeted extension services.

2. **Mobile advisory services:** Using mobile networks to send personalized SMS or interactive voice response (IVR) messages with information on weather forecasts, market prices, pest alerts, and recommended practices.
3. **Mobile applications:** Smartphone apps provide interactive tools for crop disease diagnosis using photos, calculators for input management, and access to local market data, placing information directly in farmers' hands.

4. **Social media and online platforms:** These platforms, including WhatsApp and Facebook, facilitate peer-to-peer learning and create virtual communities where farmers can share knowledge and experiences.
5. **Data analytics and AI:** Advanced technologies analyze large datasets from satellite imagery, drones, and sensor networks to provide precision farming recommendations for irrigation, nutrient management, and yield prediction.
6. **Multi-stakeholder innovation platforms:** These platforms create collaborative networks that extend beyond the public sector to include diverse actors in the agricultural value chain.
7. **Public-private partnerships (PPPs):** Collaborative arrangements between government agencies and private companies leverage private sector efficiency and resources to deliver high-quality, specialized extension services and market linkages.
8. **Innovation platforms:** These forums bring together farmers, researchers, private firms, and policymakers to jointly identify problems, co-create solutions, and coordinate technology adoption.
9. **Integrated agricultural research for development (IAR4D):** This approach embeds research within broader development contexts, ensuring that the technologies developed are aligned with farmers' needs and local conditions from the outset.
10. **Pluralistic and participatory approaches:** Shifting control from extension agents to farmers empowers them as active participants in the innovation process.
11. **Farmer-led extension:** This model leverages progressive or lead farmers as peer educators who disseminate information and demonstrate new technologies to their neighbors, fostering trust and local relevance.
12. **Farmer producer organizations (FPOs): Farmer field schools (FFS):** An educational approach that brings farmers together to experiment with and learn about new technologies in a hands-on, field-based setting, moving away from prescriptive instructions. Organizing farmers into groups strengthens their collective bargaining power for inputs, credit, and markets while serving as an effective channel for extension services.
13. **Systems-based and market-led strategies:** These approaches recognize that technology adoption is influenced by the entire farming system and market dynamics.
14. **Farming systems research and extension (FSRE):** This holistic approach considers the farm as an integrated system, addressing the complex interactions between crops, livestock, and socioeconomic factors to develop appropriate solutions.
15. **Market-led extension:** The focus is on connecting farmers to markets and adding value to their produce, thereby linking technology adoption directly to economic incentives and improved livelihoods.

Different models for Next Generation agricultural extension approaches

Models for next-generation agricultural extension approaches move beyond singular, top-down methods to embrace diverse, multi-stakeholder, and demand-driven systems. These pluralistic models leverage technology, market forces, and local knowledge to create more effective and sustainable technology transfer

1. **Digital and cyber extension models:** These models utilize Information and Communication Technologies (ICTs) to extend the reach of agricultural information and services, enabling a wider and more targeted audience.
2. **Cyber/e-Extension:** Involves the use of digital tools like websites, portals, and mobile apps to provide farmers with information on farming techniques, crop management, market prices, and weather forecasts.
3. **Expert systems:** These AI-driven systems provide farmers with expert-level decision-making assistance by emulating the knowledge and reasoning of human experts in specific fields.
4. **Mobile advisory services:** Utilize SMS, voice messages, and dedicated mobile applications to deliver timely and personalized advice to farmers, especially in remote areas.
5. **Data-driven decision-making:** Analyzes large datasets from various sources, such as satellite imagery and sensors, to provide data-backed insights for precision farming.

2. Market-led extension models

Shifting from a focus on production to market opportunities, these models integrate market dynamics into extension services to improve farmer profitability.

- A. **Value chain integration:** Involves supporting farmers throughout the entire value chain, from production to processing and marketing. This ensures production aligns with market demand and quality standards.
- B. **Market intelligence:** Extension services provide farmers with market information, consumer preferences, and business management training to help them make informed decisions.
- C. **Contract farming agreements:** Facilitate partnerships between farmers and buyers, ensuring a guaranteed market for specific produce at pre-determined prices.

3. Pluralistic extension models

This approach moves away from a single-agency system by recognizing that a range of public, private, and non-profit actors can provide effective extension services.

- A. **Public-private partnerships (PPPs):** Leverage the public sector's reach and coordination with the private sector's efficiency and innovation. These can take forms such as joint ventures for custom hiring centers or seed production.
- B. **NGO-led extension:** Non-governmental organizations (NGOs) often focus on specific issues like women's empowerment or sustainable farming practices, providing specialized services that complement public efforts.
- C. **Multi-agency collaboration:** Coordinates efforts among different government departments (e.g., agriculture, livestock), universities, and private entities to provide integrated services for farmers.

4. Farmer-led extension models

These approaches empower farmers to drive their own learning and technology transfer, leveraging local knowledge and peer networks.

- A. **Farmer-to-farmer (F2F) extension:** Utilizes selected lead or model farmers to share knowledge and skills with their peers through demonstrations and network-based interactions.
- B. **Farmer field schools (FFS):** Provides a hands-on, group-based learning environment where farmers conduct their own experiments to discover and adapt new practices.
- C. **Farmer producer organizations (FPOs):** Groups of farmers organize to enhance their collective bargaining power and facilitate the exchange of knowledge, inputs, and access to markets.

5. Systems-based approaches

This holistic model considers the farm as an entire system, taking into account the complex interactions between different enterprises and socio-economic factors.

- A. **Farming Systems Research and Extension (FSRE):** A participatory, interdisciplinary approach that develops and adapts technologies based on the specific socio-economic and environmental conditions of farmers.
- B. **Integrated farming systems (IFS):** Promotes the integration of multiple enterprises like crops, livestock, and fisheries to optimize resource use, increase profitability, and ensure sustainability.
- C. **Whole-farm planning:** Involves the creation of comprehensive farm plans, often with the help of digital tools or extension agents that consider all aspects of the farm enterprise to optimize management decisions.

Conclusion

Next-generation extension approaches are fundamentally transforming the process of technology transfer by creating a demand-driven, collaborative, and empowering ecosystem. By integrating digital technologies, fostering multi-stakeholder partnerships, and prioritizing participatory methods, these approaches overcome the limitations of traditional, top-down systems. They shift the focus from simply disseminating technology to empowering farmers as critical decision-makers and innovators. For technology transfer to be effective, it must be responsive to local context, economically viable, and sustainable. The successful implementation of these approaches requires strong policy support, capacity building for extension agents, and continuous adaptation to changing environmental and market conditions.

"Space Breeding: Cultivating Crops Beyond Earth for a Resilient Future"



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Abstract:

Space breeding, also referred to as space-induced mutagenesis, represents a groundbreaking direction in agricultural biotechnology. This innovative approach utilizes the extreme environmental conditions of outer space such as cosmic radiation, microgravity and rapid temperature shifts to induce spontaneous genetic changes in plant seeds. These alterations, often unattainable through conventional methods on Earth, can result in the emergence of plant varieties with improved traits like enhanced yield, resilience to stress, better nutritional content and increased resistance to pests and diseases. The concept began taking shape during the space exploration era of the mid-20th century, with early contributions from the Soviet Union and the United States. In recent years, the field has witnessed significant growth, with active participation from agencies like NASA and the China National Space Administration. Unlike genetic modification, which involves precise editing of DNA, space breeding fosters naturally occurring mutations, thereby gaining wider acceptance in regions where GMOs face regulatory and social resistance. A number of space-bred crops such as high-yielding rice, nutrient-enriched wheat and disease-tolerant tomatoes have successfully been integrated into commercial farming systems. Importantly, this technology also has applications beyond Earth, offering vital solutions for growing food during long-duration space missions or in extraterrestrial colonies. This article delves into the mechanisms of space breeding, highlights its agricultural achievements and evaluates its potential in enhancing food security under climate stress. As we prepare for a future in space and address mounting agricultural challenges on Earth, space breeding stands as a bold, transformative solution.

Keywords:

Space breeding, Cosmic radiation, Microgravity, Mutagenesis, Crop improvement and Astro biotechnology

Introduction

Space is rapidly emerging as a crucial frontier for agricultural research, transcending its traditional ties to satellites and astronauts. Scientists are decisively harnessing the power of the cosmos to revolutionize crop development through the groundbreaking technique of space breeding. This approach involves sending seeds into space, where they are subjected to cosmic radiation, microgravity and extreme environmental conditions. These factors actively induce spontaneous mutations in the plants' genetic code, resulting in advantageous traits that can significantly enhance agriculture.

Space breeding, initially explored during the Cold War by both Soviet and American space programs, has decisively evolved into a powerful strategy for addressing global food challenges. The journey of seeds through space is not just a novelty; it enables the cultivation and screening of these seeds on Earth to discover variants with critical advantages, including higher yields, accelerated growth, improved disease resistance and enhanced tolerance to drought and salinity. This innovative approach is set to play a crucial role in securing our food supply for the future (Zhou and Li, 2021).

The distinguishing feature of space breeding from other modern agricultural techniques is its reliance on natural mutations instead of deliberate genetic engineering. This difference has made space breeding more acceptable in areas where genetically modified organisms (GMOs) face strict regulations or public opposition. Countries such as China, Japan and Russia have been leaders in this method and several crop varieties developed through space breeding are now in commercial use.

In an era marked by climate uncertainty, a growing population and limited arable land, space breeding presents a novel and practical approach to developing resilient crops. As we prepare for long-term human settlement on the Moon and Mars, the ability to grow food beyond Earth could become not just beneficial but

essential. This article examines the science and significance of space breeding, where the intersection of agriculture and space science is paving the way for the future of food.

What is Space Breeding?

Space breeding refers to the process of developing new plant varieties by exposing seeds or other plant materials to the unique conditions of outer space. This includes exposure to cosmic radiation, microgravity, vacuum and fluctuating temperatures aboard spacecraft, satellites or space stations. The core idea is to harness the space environment to induce genetic mutations that may lead to beneficial traits, such as higher yield, disease resistance or environmental adaptability.

Techniques in Space Breeding

There are several ways by which plant materials are exposed to the space environment. These include:

- Spaceflight Exposure:** Seeds or embryos are carried aboard spacecraft, where they are subjected to the space environment during flight (Cheng *et al.* 2017).
- Satellite Carriage :** Seeds are packed in biological payloads and sent into orbit on satellites. This is a cost-effective method compared to manned missions.
- Space Station Experiments :** Facilities like China's *Tiangong space station* or the *International Space Station (ISS)* offer opportunities for more controlled and extended experiments (Khodja, 2012).

The Science Behind Space-Induced Mutations

- Cosmic Radiation and its effects on DNA:** In space, seeds are exposed to high-energy particles like protons, heavy ions and gamma rays that can penetrate cells and damage DNA. This can cause mutations in coding or regulatory regions, potentially leading to new heritable traits. While many mutations are neutral or harmful, some can enhance stress resistance or improve growth.
- The Role of Microgravity and Vacuum Conditions:** Microgravity disrupts cellular structure, nutrient transport and gene expression, creating unique physiological effects. Vacuum conditions add stress through dehydration and oxidative damage, which can destabilize genetic material. Together, these factors create a powerful mutagenic environment that accelerates plant evolution and trait development.

3. Types of Mutations and Screening Techniques

Types of Mutations:

- Point mutations:** Single base changes that may affect gene function.
- Indels:** Small insertions or deletions that disrupt gene coding.
- Chromosomal rearrangements:** Structural changes like duplications or inversions.
- Gene expression changes:** Altered regulation of protein production.

Screening Techniques:

- Phenotypic evaluation:** Observing traits like yield or stress tolerance.
- Molecular markers:** Using SSRs, SNPs or AFLPs to detect DNA changes.
- Genomic sequencing:** Identifying precise mutations in the genome.
- Gene expression profiling:** Measuring mRNA levels via qPCR or RNA-Seq.
- Proteomics & metabolomics:** Studying proteins and metabolites to assess functional changes.

Applications in Climate-Resilient Agriculture

- Drought and Salinity Tolerance:** Space-bred crops show better root systems, improved water use efficiency and salt tolerance. For example, space-mutated rice and wheat in China perform well in saline soils and water-deficit conditions (Lu, *et al.* 2008; Munns and Tester, 2008).
- Improved Nutrient Uptake:** Mutants exhibit denser root hairs and better associations with soil microbes, increasing uptake of vital minerals, which is especially beneficial for low-input farming (Wang *et al.* 2020).
- Biofortification Potential:** Some space-bred crops display elevated levels of essential nutrients like iron, zinc and antioxidants. Nutrient-rich soybeans and tomatoes offer improved public health outcomes, particularly in malnourished regions.

Future Prospects and Challenges

- International Cooperation:** Global collaboration among space agencies, research institutions and private sectors is crucial. China's Shenzhou missions and NASA's ISS experiments highlight the value of shared

resources and data. Bodies like the United Nations Office for Outer Space Affairs (UNOOSA) encourage space technologies for sustainable development (Jakhu and Pelton, 2017).

2. **Ethical and Regulatory Concerns:** Although space breeding avoids transgenic manipulation, its random nature introduces uncertainty. Key concerns include:

- **Unpredictable Mutations:** Potential for unintended harmful traits.
- **Ownership and Access:** Disputes over rights to space-bred varieties.
- **Transparency:** Whether space-bred crops should be labeled.

Most countries treat them as conventional crops, but global biosafety guidelines are needed to address equity and safety (Bonnal and Ruault, 2015).

3. **Integration with Genomics and CRISPR:** The future lies in merging space breeding with molecular tools. Space environments produce novel mutations; genomics decodes their functions; CRISPR can replicate or refine these mutations in other crops with precision. This trio creates a rapid, targeted breeding pipeline ideal for both Earth-based and space agriculture (Chen *et al.* 2019 and Song *et al.* 2022).

Conclusion:

Space breeding exemplifies the convergence of space science and plant biology. It offers a promising solution to climate-induced agricultural stress and long-term space colonization needs. With responsible governance, international collaboration and integration with modern biotechnology, space-bred crops may soon revolutionize global food systems on Earth and beyond.

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Transforming Agriculture: Using AI to Change Farming for A Better Future



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Artificial Intelligence (AI) is rapidly becoming a transformative tool in various industries, including agriculture. AI involves creating machines and computer programs capable of human-like thinking and decision-making. These systems analyze vast amounts of data, recognize patterns, make informed decisions, and provide actionable advice—capabilities previously unimaginable. Farmers worldwide face significant challenges such as climate change, food shortages, labor scarcity, and uneven food distribution.

AI offers solutions to these issues by enhancing farming methods and ensuring sufficient food production for the global population. From predicting crop yields and monitoring soil health to automating labor-intensive tasks like planting and harvesting, AI is making agriculture more efficient and environmentally sustainable (see Table 1).

In India, where agriculture plays a crucial role in the economy, AI adoption is accelerating. The AI agriculture market in India is projected to grow from USD 1.7 billion in 2023 to USD 4.7 billion by 2028. Increasing access to real-time data, smart tools, and modern technology, supported by government initiatives and private enterprises, is driving Indian farming toward more scientific, data-driven practices. This shift is critical for addressing hunger and strengthening agricultural resilience.

Table: 1. Country-Wise Implementation of AI in Modern Agriculture

Country/Region	AI Application	Technology / Use Case Example
United States	Autonomous weeding robots	Farm Wise's Titan FT 35 robot uses AI and cameras to remove weeds without using chemicals.
Germany / India	Crop advisory via mobile app	Plantix uses AI to find plant diseases from smart phone pictures and gives advice on how to treat them.
India (Telangana)	Drone & sensor-based monitoring	The World Economic Forum's AI project helps farmers get better crop yields and use fewer pesticides by monitoring crops with AI.
USA (Precision Farming)	Robotics, AI, 5G-enabled precision agriculture	In the USA, AI works with 5G, drones, and sensors to watch crops closely and run machines that work on their own.
Global (Weed Control)	Precision spraying	Carbon Robotics' Laser Weeder and John Deere's See & Spray use AI and cameras to spot weeds and spray only where needed.

Sources: Wikipedia, World Economic Forum, Business Insider, company case studies (2024–2025)

How Artificial Intelligence Can Help in Farming

AI is revolutionizing farming by boosting crop yields, predicting weather patterns, optimizing resource use, and automating complex tasks. Access to data-driven insights allows farmers to make smarter decisions, resulting in increased production, reduced waste, and more sustainable practices. The global population is expected to reach 9.7 billion by 2050, making sustainable food production essential. Despite sufficient global food production, nearly one billion people remain hungry due to challenges like food waste, climate change, and inefficient resource management. AI helps by analyzing comprehensive agricultural data—including weather, soil

conditions, crop health, and market trends—to improve farming efficiency. According to the World Economic Forum, AI has the potential to reduce pesticide use by 60% and water usage by 50%, benefiting the environment.

In India, AI adoption is advancing with support from startups and government projects. Combining AI with critical agricultural datasets (soil health, pest images, crop yields, land records) could unlock a \$65 billion opportunity, per NASSCOM and McKinsey. The following sections explore AI’s role in crop monitoring, soil management, livestock health, and sustainable farming.

Crop Health Monitoring and Management

AI technologies like drones, satellites, and smart cameras capture high-resolution images of crops. AI algorithms analyze these images to detect plant stress, diseases, or pest infestations early, enabling timely interventions and reducing crop loss. AI also predicts growth stages and harvest times, assisting farmers in planning labor and market delivery. In seed breeding, AI helps identify strong traits for developing resilient crop varieties. For example, Seed-X uses AI for gene analysis, while companies like Taranis and Blue River Technology specialize in pest and weed control through AI-driven imagery. (Table 2)

In India, neural networks detect apple diseases with 95% accuracy, and machine learning models identify wheat diseases early. The National Pest Surveillance System uses AI to alert farmers about potential pest outbreaks, safeguarding crops.

Table: 2. Use of AI in Crop Health Monitoring and Management

Application Areas	Technology used	Description / Function	Advantage
Crop Health Monitoring	Drones, satellites, smart cameras + AI	Assess plant condition via aerial/satellite images	Early detection of stress, disease, nutrient issues
Disease & Pest Detection	Taranis (aerial imagery), neural networks	Identify disease or pest signs from images/sensors	Timely intervention prevents crop loss
Precision Spraying	Blue River Technology’s “See and Spray” system	Targeted herbicide/pesticide spraying	Reduces pesticide use by up to 90%, cuts costs
Growth Prediction & Planning	ML models using historical & real-time data	Forecast crop growth and harvest timing	Better resource & labor planning
Seed Breeding & Genetic Analysis	Seed-X AI for gene analysis	Identify resilient plant traits and breed varieties	Develops high-yield, disease-resistant crops
Government Surveillance	India’s National Pest Surveillance System	Pest tracking and alerts	Protects crops regionally
Machine Learning in Wheat	Custom ML visual diagnosis	Early wheat disease detection	Preserves yields, minimizes chemical use

Source: Based on company case studies and government reports (2024–2025)

Soil Health Analysis and Management

Healthy soil is essential for productive farming, and AI-based tools are revolutionizing soil analysis and management. Devices like the Agro Cares Nutrient Scanner provide real-time nutrient diagnostics, enabling farmers to apply fertilizers more precisely and efficiently. The Teralytic Soil Probe monitors 26 soil health parameters, including nitrogen, pH, and salinity, offering comprehensive insights into soil conditions. Similarly, the CropX Soil Sensor integrates moisture and temperature data with AI to optimize irrigation and fertilizer timing, reducing input waste and enhancing crop yields while promoting sustainable land use.

In India, AI-driven soil health tools are making significant impacts as well. Innovations such as IIT Bombay’s Proximal Soilsens and a handheld AI-based soil analyzer developed by a retired ISRO scientist provide real-time data on soil nutrients and moisture. These advancements help Indian farmers optimize fertilizer application and irrigation practices, improving productivity and supporting long-term soil fertility and eco-friendly farming. Together, these technologies are paving the way for more sustainable and efficient agriculture (Table 3).

Table: 3. AI-Based Soil Testing Equipment and Their Applications

Equipment	Technology Used	Function	Key Benefits
Agro Cares Nutrient Scanner	AI + Spectroscopy + Cloud Data	Analyzes soil nutrients (NPK, pH, organic matter)	Instant soil test results; improves fertilizer efficiency
Crop In Smart Farm	AI + IoT + Satellite Data	Monitors soil health via mobile & IoT-based integration	Precision in soil mapping and nutrient application
Soil Cares Scanner	AI Algorithms + Near Infrared Spectroscopy	Portable device for real-time soil fertility analysis	Fast and lab-free soil testing; supports remote farming
Arable Mark	AI + Sensor Fusion + Machine Learning	Tracks soil moisture, microclimate, and plant health	Helps in smart irrigation and soil-water balance
Teralytic Soil Probe	AI + Wireless IoT Sensors	26-sensor probe measuring NPK, salinity, pH, temp, moisture	Real-time 3D soil profiling; promotes sustainable usage
E Soil Systems	AI + Electrochemical Sensing	Provides electrochemical-based soil testing	Accurate nutrient detection; enhances soil decision-making
RML Ag Tech Devices	AI + Mobile Integration	Soil analysis through smart phone-connected sensors	Affordable tech for smallholder farmers

AI in Livestock and Dairy Health Monitoring

AI applications extend to animal husbandry, improving livestock health and dairy productivity. Sensors and cameras track vital signs such as temperature, heart rate, and movement, allowing early detection of illness and behavioral changes. In dairy farming, AI monitors milk yield and identifies health issues like mastitis, ensuring high milk quality and efficient production. Technologies such as Cattle Eye use AI and computer vision for early lameness detection, enhancing animal welfare and reducing productivity losses. (Table 3)

Table: 3. AI in Livestock and Dairy Health Monitoring

Functional Area	AI Technology	Description / Function	Advantages
Animal Health Monitoring	AI wearables, thermal cameras, smart collars	Tracks vitals to detect illness early	Early illness detection, reduced veterinary costs
Behavior Analysis	Motion sensors + AI behavior models	Detects abnormal behavior	Disease prevention, timely treatment
Dairy Monitoring	Smart milking systems + AI diagnostics	Analyzes milk yield and quality	Maintains milk quality, improves efficiency
Lameness Detection	Cattle Eye AI + computer vision	Identifies mobility issues	Improves welfare, reduces losses
Remote Livestock Management	AI + video surveillance	Monitors health and behavior remotely	Reduces labor, useful for large/remote farms
Reproductive Health Tracking	AI algorithms analyzing movement & behavior	Predicts estrus cycles and breeding health	Increases breeding efficiency
Feed Optimization	IoT feeding systems + AI analytics	Tracks feed intake, adjusts diets	Reduces feed waste, enhances growth & yield

Source: Derived from industry use cases and AI-agritech company solutions (2024–2025)

Government Initiatives Supporting AI in Agriculture

The Indian government is actively promoting AI in agriculture to address low productivity, climate risks, and pest challenges. Under the national initiative “Make AI in India and Make AI Work for India,” three AI Centres of Excellence (CoEs) focusing on agriculture, healthcare, and smart cities have been established with a budget of ₹990 crore (2023–2028) to develop AI solutions for farmers and rural communities.

Important Government AI Projects

- **Kisan e-Mitra Chatbot:** An AI chatbot that interacts in multiple languages, providing farmers with information on government schemes, weather forecasts, crop advice, and market prices.
- **AI-Based Crop Health Monitoring:** Utilizes satellite and sensor data to assess crop health, enabling farmers to take early action.
- **National Pest Surveillance System:** Tracks pest movements using AI to alert farmers and prevent crop damage.

Chatbots as Virtual Farm Helpers

Beyond government projects, AI chatbots are emerging as digital assistants to help farmers manage tasks, communicate with buyers, and track supplies. For instance, Microsoft’s FarmVibes chatbot uses natural language processing and AI to provide personalized advice based on weather, soil, and market data. Over 500,000 farmers in Africa currently use it, and similar adoption in India could significantly benefit small-scale farmers. By combining large-scale government initiatives with user-friendly AI chatbots, India is expanding AI access to all farmers, particularly those in rural areas who form the backbone of its agricultural sector.

Precision Farming and Autonomous Machines: Changing Modern Farming

AI is transforming farming through precision agriculture and autonomous machinery, enabling better decision-making and automation of labor-intensive tasks. In precision farming, AI integrates data from drones, sensors, and satellites to monitor soil, moisture, pests, and crop health in real time. This allows for precise application of water, fertilizers, and pesticides—minimizing waste, saving costs, and increasing yields. Autonomous machines like self-driving tractors and robotic harvesters use AI combined with GPS to perform tasks such as planting, fertilizing, and harvesting with high accuracy. These machines reduce the need for manual labor and help farmers manage fields efficiently. Together, precision farming and AI-powered machinery are making agriculture more productive, sustainable, and future-ready (Table 4).

Table 4. AI-Powered Machines in Precision Farming & Their Uses

Devices/Technology	Technology Used	Mode of Operation	Function / Use
Autonomous Tractors	AI + GPS + Sensors	Self-driving vehicle	Plowing, planting, spraying, harvesting
John Deere See & Spray	Machine learning + Cameras	Smart sprayer	AI vision detects weeds, sprays herbicide only where needed
Carbon Robotics Laser Weeder	Computer vision + AI + Laser technology	Robotic weeder	Uses lasers and AI vision to destroy weeds without chemicals
Farm Wise Titan FT-35	AI + Computer vision	Weeding robot	Mechanical weed removal, reducing herbicide use
Agrobot E-Series	AI + Robotics + Vision systems	Fruit-harvesting robot	Detects and harvests ripe strawberries
Blue River Technology Machines	AI + Precision vision + Robotics	Smart ag equipment	Automates fertilizing, spraying, weeding using AI image recognition
Ecorobotix ARA	Deep learning + Computer vision	Autonomous sprayer	Targeted herbicide application
Naïo Technologies Robots (Oz, Dino)	AI + GPS + Robotic navigation	Field robots	Weeding and hoeing in vegetable/vineyard crops
Precision Drone Systems (DJI Agras)	AI + Remote sensing + Aerial imaging	Agricultural drones	Crop monitoring, spraying, mapping
Autonomous Combine Harvesters	AI + GNSS + Real-time mapping	Self-driving harvester	Harvests crops efficiently using GPS guidance
Smart Soil Sensors	IoT + AI data analytics	Stationary IoT device	Monitors soil moisture, pH, nutrients
Auto Turn & Auto Trac (John Deere)	GPS + AI-powered steering systems	Tractor guidance system	Precise steering and automatic field turns
Smart Irrigation Controllers	AI + Sensor integration	Automated irrigation	Adjusts watering based on real-time data

Source: Compiled from technology manufacturer data and industry reports (2024–2025)

Market Intelligence: Using AI to Understand Agricultural Demand

Artificial Intelligence plays a vital role in helping farmers anticipate market demand by analyzing vast datasets, including weather trends, satellite imagery, historical crop yields, and market fluctuations. Companies like Descartes Labs use AI to suggest the best crops to grow and the ideal times to plant, enabling farmers to align production with market needs. This prevents overproduction or shortages, helping stabilize prices and reduce losses. AI-driven market intelligence supports better planning, increases profitability, and promotes sustainable farming by optimizing land and resource use. Ultimately, it empowers farmers with data-driven insights for smarter agricultural decisions (Table 5).

Table: 5. AI-Driven Market Intelligence for Agricultural Demand Forecasting

Parameters/Components	Platforms/Agency	Description	Advantages
Weather Pattern Analysis	Various AI platforms	Uses AI to analyze climate and weather forecasts to guide planting and harvesting schedules	Helps optimize timing for planting and harvesting
Satellite Image Analysis	Descartes Labs	Monitors crop health and land conditions via satellite data	Enables real-time field assessment and decision-making
Historical Yield Data	Descartes Labs	Examines past yield trends to forecast future production	Supports planning to avoid overproduction or shortages
Current Market Trends	AI-driven market analytics	Analyzes demand, prices, and consumption patterns	Helps align crop choice with market demand
Crop Choice Recommendations	Descartes Labs	Suggests best crops to plant based on integrated data analysis	Maximizes profitability and reduces risks
Risk Reduction	AI market intelligence	Minimizes risk of overproduction and market gluts	Enhances income stability and efficient resource use
Sustainable Land Use	AI tools in agriculture	Promotes balanced use of land based on predicted demand	Supports long-term soil health and environment

Source: Compiled from industry reports and company case studies (2024–2025)

Conclusion

AI is rapidly transforming agriculture, offering substantial benefits to farmers and the environment. It enhances efficiency, supports sustainable farming, increases productivity, and boosts farmers' incomes. AI applications range from crop health monitoring and soil management to livestock care and market forecasting, opening new opportunities for data-driven agriculture. However, challenges remain. AI technologies can be costly to implement, and automation may reduce labor demand in some areas. AI systems are not infallible and should complement, not replace, farmers' expertise. For small-scale farmers, especially in rural India, AI solutions from companies like Jiva are helping bridge knowledge gaps and provide accessible, transparent farming assistance. By balancing innovation with caution, AI can play a pivotal role in building a sustainable, productive future for global agriculture.