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Cisgenics and Intragenics: Natural Genes, Novel Solutions

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Abstract

For decades, the debate around genetically modified (GM) crops has been polarized, balancing their potential for improving food security against concerns about foreign genes and environmental impact. However, a new wave of genetic technologies is emerging that could bridge this divide. Cisgenesis and intragenesis are innovative plant breeding techniques that, unlike traditional transgenesis, use only genetic material from the plant species itself or from closely related, sexually compatible species. This article explores how these methods offer a more precise and natural approach to crop improvement. By transferring genes complete with their native regulatory elements (cisgenesis) or creating new, optimized combinations of genes and promoters from the same gene pool (intragenesis), breeders can develop crops with desirable traits such as disease resistance and improved nutritional quality, without the "linkage drag" of conventional breeding and without introducing foreign DNA. We delve into the science behind these techniques, showcase their successful application in crops like apples, potatoes and barley and discuss the ongoing regulatory and public perception challenges. As the global population grows and climate change intensifies, cisgenics and intragenics present a promising, publicly palatable tool to accelerate the development of sustainable and resilient crops.

Keywords: Cisgenics, Intragenics, Crop Improvement, GMO, Sustainable Agriculture, Disease Resistance, Food Security, Plant Breeding.

Introduction

Crop improvement has historically relied on selective breeding, wherein superior plants were crossed over successive generations to enhance yield, quality and resilience. Although effective, this approach is inherently slow and often requires more than a decade to develop a new variety. The advent of genetic engineering in the late 20th century marked a significant milestone, enabling the direct introduction of genes across species barriers. Transgenesis, which involves the incorporation of genes from unrelated organisms such as bacteria into plants, has facilitated the development of crops with resistance to pests and herbicides, thereby contributing to substantial yield gains (Vasudevan *et al.*, 2023).

Despite these benefits, the deployment of transgenic crops has been accompanied by considerable controversy. Public concerns regarding ecological safety, potential health risks and the perception of “unnatural” inter-kingdom gene transfer have restricted their acceptance, particularly in Europe and several other regions (Daye *et al.,* 2023). This situation has created a critical challenge for agricultural biotechnology: achieving rapid and precise crop improvement while maintaining public trust and navigating stringent regulatory frameworks.

To address these limitations, emerging approaches such as cisgenesis and intragenesis have been proposed. Both techniques utilize only genetic material derived from the crop’s own gene pool or sexually compatible species, thereby aligning more closely with conventional breeding principles. For instance, the transfer of a scab-resistance gene from a wild apple genotype into a commercial cultivar like ‘Gala’ can be accomplished directly through cisgenesis, without the extensive backcrossing required in traditional breeding. This strategy not only preserves the desirable genetic background of elite cultivars but also accelerates the breeding process, reducing timelines from decades to a few years (Vanblaere *et al.*, 2011). Consequently, cisgenesis and intragenesis represent promising alternatives to transgenesis, offering both precision and improved societal acceptance in the development of next-generation crop varieties.

The Science Simplified: Cisgenesis vs. Intragenesis

At its core, both cisgenesis and intragenesis are about genetic precision using native DNA. However, a key distinction lies in how they assemble the genetic components.

Cisgenesis is the cut-and-paste method. It involves transferring a natural gene, including its promoter (the "on" switch), introns and terminator (the "off" switch) intact from a sexually compatible donor plant (like a wild relative) into a cultivated variety. The resulting cisgenic plant is genetically indistinguishable from one that could theoretically be produced through conventional breeding, just much faster and without linkage drag (Schouten *et al.*, 2006). Think of it as moving a complete, pre-assembled instruction manual from one book to another within the same library.

Intragenesis is the cut, shuffle and paste method. It also uses genetic elements from the same or closely related species but allows scientists to create *new combinations*. For example, a gene for disease resistance could be paired with a strong, tissue-specific promoter from a different native gene to ensure the resistance is highly active in the plant's leaves (Rommens, 2004). This flexibility allows for more nuanced control, such as enhancing a trait (overexpression) or silencing an undesirable one. Intragenesis can even use gene fragments to turn off specific genes, a process known as silencing.

Key differences between Cisgenesis and Transgenesis.

Feature	Cisgenesis	Intragenesis
Gene of Interest	Complete, intact copy of a natural gene.	Can be a complete gene or a fragment, in sense or anti-sense orientation.
Regulatory Elements	The gene's native promoter and terminator.	New combinations; a promoter from one gene can be linked to the coding sequence of another.
Key Concept	Faithful reconstruction of a natural allele.	In vitro recombination and optimization of genetic elements from the same gene pool.

A crucial technological advancement in both approaches is the elimination of selectable marker genes (often antibiotic resistance genes from bacteria), which are used in the lab to identify successfully transformed plants but are undesirable in the final product (Fig. 1). Techniques like the Cre-lox system allow scientists to remove these marker genes after they have served their purpose, leaving behind a "clean" plant with only the desired cisgenic or intragenic DNA (Zuo *et al.*, 2001).

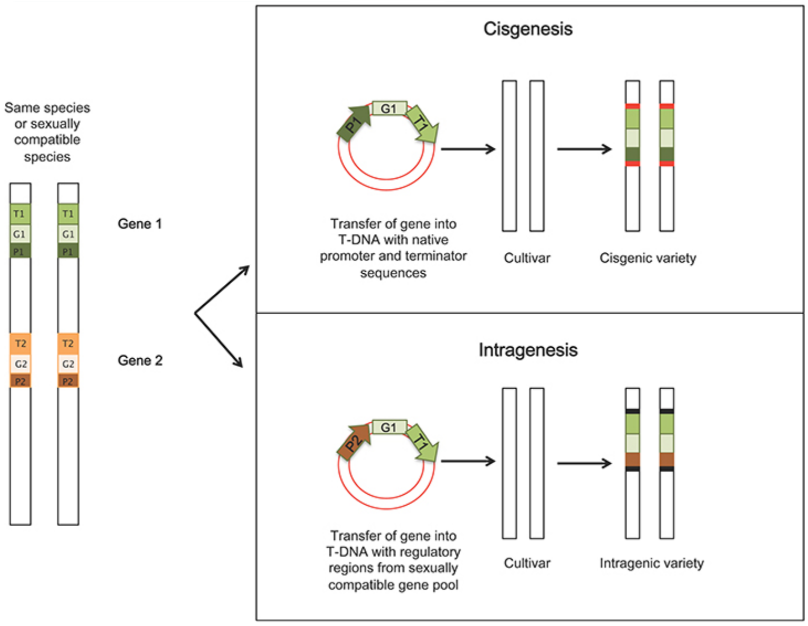

Fig. 1. Approaches to generate cisgenic and intragenic crops (Limera *et al.*, 2017)

Success Stories from the Orchard to the Field

The potential of these techniques is not merely theoretical. They have been successfully demonstrated in several important crops, offering tangible solutions to agricultural problems.

1. The Scab-Resistant Apple: Apples are highly susceptible to apple scab, a devastating fungal disease. A wild apple, *Malus floribunda*, possesses a natural resistance gene (*Rvi6*). Using cisgenesis, scientists transferred this entire gene into the popular 'Gala' apple. The resulting cisgenic apples showed strong resistance to scab in both greenhouse and field trials, without the decades of breeding and the poor fruit quality traits that often come from the wild relative (Vanblaere *et al.*, 2011). Similarly, intragenic apples were created by driving the same *Rvi6* gene with a promoter from a different plant gene, also proving effective.

2. The Healthier, Non-Browning Potato: Potatoes are prone to bruising and enzymatic browning, leading to waste and undesirable black spots on chips and fries. Furthermore, when fried at high temperatures, potatoes can produce acrylamide, a potential carcinogen. Using intragenesis, researchers silenced specific potato genes:

- Silencing *Polyphenol Oxidase (PPO)* genes reduced browning.
- Silencing *Asparagine Synthetase* genes reduced the accumulation of asparagine, an amino acid that forms acrylamide during frying.

The result was an intragenic potato line that produced up to 70% less acrylamide when fried, addressing a significant consumer health concern while improving product quality (Chawla *et al.*, 2012).

3. The Environment-Friendly Barley: A major environmental issue with livestock farming is water pollution from manure. A significant portion of the phosphorus in animal feed, such as barley, is locked up in a compound called phytate and passes undigested through the animal. Researchers used cisgenesis to overexpress a native barley phytase enzyme (*HvPAPhy_a*) in the grain. This enzyme breaks down phytate, making the phosphorus available to the animal. This means less phosphorus is excreted, reducing algal blooms and eutrophication in waterways, while also improving the animal's nutrition (Holme *et al.*, 2013).

Other examples include cisgenic durum wheat with improved baking quality, intragenic lucerne (alfalfa) with lower lignin for better animal feed and poplar trees with modified growth rates and wood properties for more efficient biomass production.

Advantages, Concerns and the Regulatory Maze

- **Speed and Precision:** Cisgenesis/intragenesis can introduce a specific trait into a high-quality elite cultivar in a single generation, bypassing 15-20 years of backcrossing.
- **No Linkage Drag:** Only the gene of interest is transferred, leaving behind undesirable genes linked to it in the donor plant.
- **Expanding the Gene Pool:** They allow breeders to tap into the vast reservoir of beneficial genes in wild relatives without the associated drawbacks of traditional crossing.
- **Public Acceptance:** Initial studies and surveys suggest that consumers view cisgenic and intragenic crops more favorably than transgenic ones, as they are perceived as a more natural extension of conventional breeding (Daye *et al.*, 2023).

Addressing the Concerns

Despite the advantages, these technologies are not without questions.

- **Random Insertion:** Like early transgenesis, the current methods can lead to random insertion of the new gene into the plant's genome, which could potentially disrupt existing genes or have unintended effects. However, it's important to note that conventional breeding also involves random genetic rearrangements.
- **Regulatory Uncertainty:** The biggest hurdle remains regulation. In most countries, including the United States and members of the European Union, cisgenic and intragenic crops are currently regulated under the same strict laws as transgenic GMOs (Ewen *et al.*, 2022). This classification imposes a high cost and lengthy approval process, limiting their development to large corporations and hindering public research institutions.

The scientific consensus, however, is shifting. The European Food Safety Authority (EFSA) has stated that the risks associated with cisgenic/intragenic plants are not different from those of conventionally bred plants and that their risk assessment could be simplified on a case-by-case basis (Ewen *et al.*, 2022). There are ongoing debates and proposals, particularly in Europe, to exempt this category of plants from the stringent GMO regulatory framework, recognizing their closer kinship to traditional breeding.

Conclusion: A Promising Tool for a Sustainable Future

Cisgenics and intragenics represent a significant evolution in our ability to improve crops. By marrying the precision of genetic engineering with the genetic boundaries respected by traditional breeders, they offer a powerful, socially acceptable and environmentally sound path forward. They allow us to rapidly fortify our food crops against diseases, pests and a changing climate while improving their nutritional value and reducing agriculture's environmental footprint.

While challenges related to regulation and public communication remain, the potential benefits are too great to ignore. As research progresses and genome-editing tools like CRISPR are integrated to make the process even more precise, the line between conventional breeding and genetic engineering will continue to blur. For a world in need of sustainable and resilient agricultural solutions, cisgenics and intragenics are not a bane, but a clear boon - a next-generation toolkit to cultivate a healthier and more food-secure future.

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Geriatric Food: Old Age People Food

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Abstract

Geriatric nutrition is an emerging field aimed at addressing the unique dietary needs of the elderly population. With physiological aging comes a decline in nutrient absorption, appetite, and metabolic efficiency, necessitating specially formulated food products. Geriatric food is developed to be nutrient-dense, easy to consume, and supportive of common age-related health conditions such as osteoporosis, sarcopenia, and cognitive decline. This article presents a comprehensive overview of geriatric food, its formulation principles, functional requirements, processing techniques, and future trends. The importance of sensory appeal, safety, and ease of digestion is also emphasized. The study concludes that geriatric food holds vital potential in enhancing the quality of life and overall health of older adults.

The aging population is rapidly increasing worldwide, necessitating innovations in healthcare, including nutrition. Geriatric food refers to specially formulated food products designed to address the unique nutritional, physiological, and sensory needs of older adults. As aging is associated with several challenges—such as reduced appetite, impaired chewing and swallowing, poor nutrient absorption, and chronic diseases—there is an urgent need to develop food that is not only nutrient-rich but also easy to digest, palatable, and safe. Geriatric foods aim to prevent malnutrition, maintain functional independence, and improve quality of life in elderly individuals. These foods are often enriched with high-quality proteins, omega-3 fatty acids, dietary fiber, and micronutrients like calcium, vitamin D, B12, and antioxidants, tailored to reduce the risk of conditions such as osteoporosis, sarcopenia, cardiovascular disease, and cognitive decline. This article provides an in-depth technical review of the formulation principles, functional and sensory characteristics, processing techniques, and health benefits of geriatric food. The study highlights the need for personalized nutrition strategies, food safety assurance, and sensory optimization to improve compliance and health outcomes in geriatric populations (Kaiser et al., 2010; Ahmed & Haboubi, 2010).

Keywords: Nutraceuticals; RDA; Antioxidant; Nutrition, Weight loss, Diet, Geriatric.

Introduction:

The aging population is increasing rapidly worldwide. According to the World Health Organization (WHO), by 2050, the number of people aged 60 and over is expected to double (World Health Organization, 2021). Aging is accompanied by physiological changes such as reduced digestive efficiency, altered taste and smell perception, dental issues, and a decrease in physical activity. These changes contribute to the risk of malnutrition, which in turn affects immunity, muscle mass, bone health, and cognitive function (Morley, 2001).

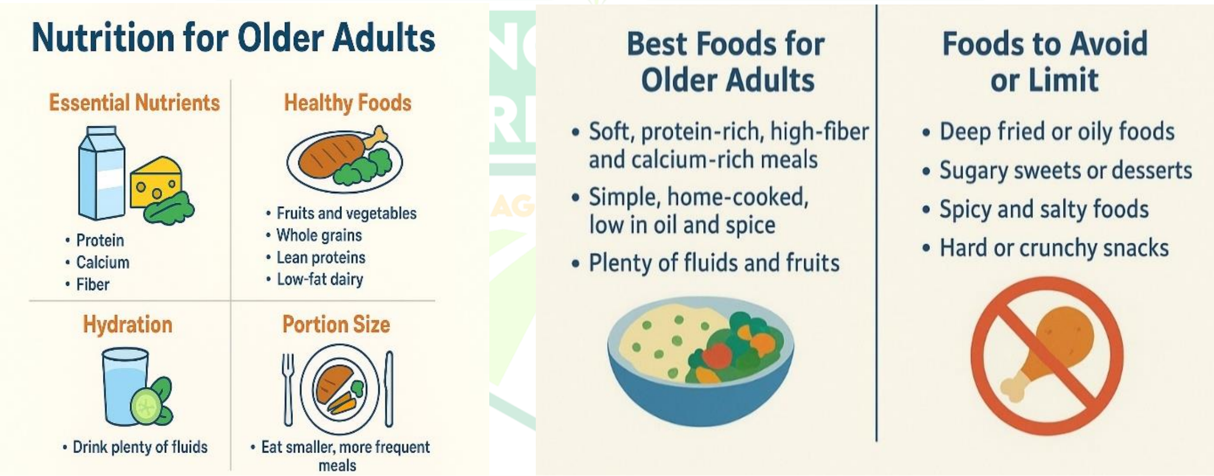
Geriatric food, therefore, plays a critical role in maintaining health and well-being. It includes specialized formulations rich in proteins, fibers, essential vitamins, and minerals, while also being soft in texture, easily digestible, and palatable. This article explores the technological, nutritional, and sensory aspects of geriatric food, as well as its potential applications and market trends.

Aging is a natural, inevitable process marked by progressive physiological, metabolic, and psychological changes that affect nutritional status and overall well-being. The elderly population (defined as individuals aged 60 years and above) is the fastest-growing demographic group globally. According to the World Health Organization (WHO), by 2050, the global population of people over the age of 60 is projected to reach over 2 billion (World Health Organization, 2021). This demographic shift presents new challenges for healthcare systems, particularly in the domain of nutrition and diet-related health management.

As people age, a variety of factors influence their nutritional needs and dietary habits: Physiological changes, such as decreased basal metabolic rate (BMR), reduced gastrointestinal function, and altered hormone regulation, affect the digestion, absorption, and metabolism of nutrients (Roberts & Rosenberg, 2006). Sensory impairments, including diminished taste, smell, and visual acuity, reduce food enjoyment and appetite (Schiffman, 1997). Oral health problems, like tooth loss or dry mouth (xerostomia), can limit the types of food an individual can consume comfortably (Sheiham & Steele, 2001).

Chronic diseases such as diabetes, hypertension, osteoporosis, arthritis, cardiovascular diseases, and neurodegenerative conditions are more prevalent in older adults and require specialized dietary management (Volkert et al., 2019). Polypharmacy, or the use of multiple medications, can further complicate nutrient absorption and utilization, leading to deficiencies or adverse interactions (Genser, 2008). These challenges can lead to protein-energy malnutrition, vitamin and mineral deficiencies, sarcopenia (loss of muscle mass), immune dysfunction, and increased risk of falls, fractures, and hospitalizations (Cederholm et al., 2017). Thus, nutrition plays a critical role not only in disease prevention and management but also in maintaining independence and life quality among the elderly.

Geriatric food refers to scientifically designed, functional food products tailored to the physical, metabolic, and psychological needs of older adults. These foods are typically: High in nutrient density but low in volume, catering to smaller appetites (Drewnowski & Shultz, 2001); Soft or easy-to-chew and swallow (Cichero, 2013); Fortified with essential nutrients such as calcium, vitamin D, B12, iron, folic acid, and omega-3 fatty acids (Allen, 2009); Modified for texture and taste to enhance palatability and sensory appeal (Kremer et al., 2007); Suitable for specific medical conditions (e.g., diabetes-friendly foods, low-sodium meals, renal-friendly diets) (Fouque & Laville, 2009).



Some of the most essential Nutraceuticals are: -

- Antioxidants (Lobo et al., 2010)
- Plant polyphenols and catechins: Turmeric, green tea, grape seed etc. (Pandey & Rizvi, 2009)
- Carotenoids: Lutein, zeaxanthin, and lycopene (Rao & Rao, 2007)
- Plant phenols/sterols (phytosterols) (Ostlund, 2002)
- Omega-3 fatty acids (Swanson et al., 2012)
- Glucosamine, chondroitin, collagen and quercetin (Reginster et al., 2001)
- Prebiotics and probiotics (Guarner & Malagelada, 2003)
- Coenzyme Q10 (Littarru & Tiano, 2007)

Best Foods for Old Age People:

Soft, protein-rich, high-fiber, and calcium-rich meals, Simple, home-cooked, low in oil and spice, plenty of fluids and fruits, Meals should be small, frequent, and easy to chew (Nieuwenhuizen et al., 2010).

Mostly Preferred Food for Old Age People

Soft and Easy-to-Digest Foods: Older adults often have weaker digestion or dental issues. Examples: Khichdi (rice + dal mash), Idli, poha, upma, Vegetable soup, Dalia (broken wheat porridge), Steamed vegetables (Cichero, 2013; Suominen et al., 2007).

High-Protein Foods: To maintain muscle and prevent weakness. Examples: Boiled eggs, Milk, curd, paneer, Lentils (dal), beans, soft fish or chicken (well-cooked), Soya chunks or tofu (Paddon-Jones & Rasmussen, 2009).

High-Calcium Foods: For strong bones and to prevent osteoporosis. Examples: Milk and curd, Ragi (finger millet), Almonds and sesame seeds, Leafy greens like spinach, Fortified cereals (Weaver et al., 2016).

Fiber-Rich Foods: To prevent constipation, which is common in old age. Examples: Whole grains (brown rice, oats, whole wheat), Fruits like papaya, banana, apple (peeled), Vegetables like carrots, beans, pumpkin, Isabgol (psyllium husk) if needed (Anderson et al., 2009).

Iron-Rich Foods: To prevent fatigue and anaemia. Examples: Spinach and green leafy vegetables, Jaggery (in moderation), Legumes (chana, moong), Dates and raisins, Iron-fortified grains (Clark, 2008).

Healthy Fats: To support brain and heart health. Examples: Nuts (in small amounts: almonds, walnuts), Seeds (flaxseed, chia), Olive oil or ghee (in moderation), Avocado (if available) (Swanson et al., 2012).

Hydrating Foods: To prevent dehydration (common in elderly people who forget to drink water). Examples: Water-rich fruits: watermelon, cucumber, Buttermilk, coconut water, Herbal teas, Clear vegetable soups (Hooper et al., 2014).

Foods to Avoid or Limit in Old Age: Food Reason to Avoid**,**

- **Deep fried or oily foods:** Hard to digest (Grotto & Zied, 2010)
- **Sugary sweets or desserts:** Risk of diabetes (Hu, 2011)
- **Spicy and salty foods:** High BP and gastric problems (He & MacGregor, 2010)
- **Hard or crunchy snacks:** Dental issues (Sheiham & Steele, 2001)
- **Too much red meat:** Hard on digestion (Abete et al., 2014)

Nutrient Why It's Important Food Sources

- **Protein:** Builds muscles, prevents weakness. Eggs, lentils, milk, chicken (Paddon-Jones & Rasmussen, 2009).
- **Calcium:** Keeps bones strong. Milk, yogurt, ragi, almonds (Weaver et al., 2016).
- **Fiber:** Helps digestion and prevents constipation. Fruits, vegetables, whole grains (Anderson et al., 2009).
- **Iron:** Prevents anaemia (weakness, fatigue). Spinach, jaggery, beans (Clark, 2008).
- **Vitamins (A, B12, D):** Support vision, brain, immunity. Carrots, dairy, sunlight, fish (Johnson, 2002; Allen, 2009; Holick, 2007).
- **Healthy Fats:** Brain and heart health. Nuts, seeds, olive oil (Swanson et al., 2012).
- **Water:** Prevents dehydration. Drinking water, soups, fruits (Hooper et al., 2014).

Examples of Healthy Meals for Elderly:

- Soft khichdi with vegetables (Suominen et al., 2007)
- Ragi or oats porridge (Weaver et al., 2016; Anderson et al., 2009)
- Boiled egg with milk or curd (Paddon-Jones & Rasmussen, 2009)
- Vegetable soup or dal soup (Cichero, 2013)
- Idli with chutney (low spice) (Suominen et al., 2007)
- Fruit salad or banana with curd (Anderson et al., 2009)

Special Considerations:

- Food should be easy to chew and digest (Cichero, 2013)
- Low in salt, sugar, and oil (Grotto & Zied, 2010; Hu, 2011; He & MacGregor, 2010)
- Avoid hard or spicy foods (Sheiham & Steele, 2001; He & MacGregor, 2010)
- Meals should be small and frequent rather than one large meal (Nieuwenhuizen et al., 2010)
- Include soups, smoothies, or soft foods for those with dental issues (Sheiham & Steele, 2001; Cichero, 2013)

Factors Affecting Nutrition in Older Adults

The nutrition of elderly people is influenced by physical, psychological, and social changes that come with aging. As the body ages, metabolism, body composition, and nutrient absorption shift, so diet needs to be adjusted accordingly (Roberts & Rosenberg, 2006).

- **Metabolism Changes:** With age, the body's metabolic rate slows down. This means older adults may need fewer calories, but their requirement for nutrients like protein, calcium, and vitamin D increases to maintain bone strength and muscle health (Roberts & Rosenberg, 2006; Elia et al., 2000).
- **Nutrient Absorption:** The body becomes less efficient at absorbing certain vitamins and minerals with age. This can lead to deficiencies, so eating nutrient-rich foods becomes very important (Russell, 2000).
- **Hydration:** Older adults often feel less thirsty and kidney function also declines. This raises the risk of dehydration, which can affect memory, digestion, and overall well-being (Hooper et al., 2014; Stookey et al., 2005).
- **Chronic Illnesses:** Conditions such as diabetes, heart disease, and osteoporosis are more common in older age. Nutrition plays a key role in managing these conditions and improving quality of life (Volkert et al., 2019).

Challenges in Geriatric Nutrition

Meeting the nutritional needs of older adults is challenging due to several age-related issues.

- **Malnutrition:** Reduced appetite, poor absorption, and long-term illnesses can cause malnutrition, leading to weakness, loss of muscle, tiredness, and lower immunity (Cederholm et al., 2017; Stratton et al., 2003).
- **Dental Issues:** Problems with teeth and gums make chewing and swallowing difficult. Seniors may prefer soft foods, which can limit the variety of nutrients they consume (Sheiham & Steele, 2001).
- **Medication Effects:** Many elderly people take multiple medicines, some of which affect appetite or interfere with nutrient absorption. This needs careful monitoring (Genser, 2008).
- **Social Isolation:** Seniors who live alone or feel lonely may skip meals or lose interest in cooking, which can reduce their overall food intake and nutrition (Locher et al., 2005).

Strategies to Improve Nutrition in Older Adults

Balanced meals: Seniors should be encouraged to eat a wide range of foods, including fruits, vegetables, whole grains, lean proteins, and dairy or alternatives. Getting enough vitamins and minerals helps prevent illness and supports good health (de Groot & van Staveren, 2002).

Protein-rich foods: Protein is very important for older adults to maintain muscle strength, strong bones, and immunity. Sources like lean meats, poultry, fish, eggs, dairy products, and plant-based proteins should be included regularly (Paddon-Jones & Rasmussen, 2009; Bauer et al., 2013).

Staying hydrated: Older adults often drink less water, which can cause dehydration. Reminding them to drink fluids and eat water-rich foods such as fruits and vegetables can help. Simple checks like monitoring urine color can guide hydration (Hooper et al., 2014; Stookey et al., 2005).

Exercise and movement: Regular physical activity keeps muscles and bones strong, supports independence, and lowers the risk of falls. When paired with good nutrition, it improves overall health (Nelson et al., 2007).

Routine health monitoring: Frequent check-ups allow early detection of nutrient deficiencies or other health problems. This ensures that diet and lifestyle advice can be adjusted to meet changing needs (Sahyoun et al., 2004).

Social connections: Eating with others and staying socially active can improve appetite and encourage healthier eating habits. Community involvement and shared meals also help reduce feelings of loneliness (Locher et al., 2005).

What Nutrients Are Essential for Older Adults?

Understanding the nutritional requirements of the elderly is crucial for ensuring they receive the nutrients necessary to maintain their health. Here are some essential nutrients that should be included in a diet for elderly individuals:

- **Calcium and Vitamin D:** Essential for maintaining bone health and preventing osteoporosis, common in older adults. Sources include dairy products, fortified cereals, and green leafy vegetables (Weaver et al., 2016; Holick, 2007).
- **Protein:** Vital for maintaining muscle mass, which naturally decreases with age. Incorporate lean meats, fish, eggs, and plant-based proteins like beans and lentils into meals (Paddon-Jones & Rasmussen, 2009; Bauer et al., 2013).
- **Fiber:** Important for digestive health and preventing constipation. A diet rich in whole grains, fruits, vegetables, and legumes ensures adequate fibre intake (Anderson et al., 2009).
- **Vitamin B12:** The body's ability to absorb vitamin B12 diminishes with age, so consuming fortified foods or supplements is crucial. This vitamin is essential for good brain health and red blood cell formation (Allen, 2009).
- **Potassium:** Helps regulate blood pressure and supports cardiovascular health. Bananas, oranges, potatoes, and beans are good sources of potassium (He & MacGregor, 2008).
- **Magnesium:** This mineral supports numerous bodily functions, including muscle and nerve function, and is often under-consumed by older adults. Foods rich in magnesium include nuts, whole grains, and leafy green vegetables (Volpe, 2013).
- **Folate:** Folate is essential for cell division and can help prevent anaemia. To meet the recommended intake, older adults should include fortified cereals, legumes, and leafy greens in their diets (Stover, 2004).

Importance of a Healthy Diet for the Elderly

Nutrition for elderly individuals plays a vital role, as dietary habits are directly linked to overall health, physical condition, and quality of life. Here are key reasons why a healthy diet for the elderly is essential:

- **Prevention of Chronic Diseases:** A well-balanced diet for the elderly can significantly reduce the risk of chronic conditions such as heart disease, high blood pressure, type 2 diabetes, and certain cancers. Nutritional deficiencies are common among senior citizens, making proper nutrition essential for preventing and managing these diseases (Volkert et al., 2019; Hu, 2002).
- **Cognitive Health:** Good nutrition for elderly individuals supports brain health, lowering the risk of cognitive decline and dementia. Anti-inflammatory nutrients, such as omega-3 fatty acids found in fish, are beneficial for maintaining cognitive function (Swanson et al., 2012; Gómez-Pinilla, 2008).
- **Bone and Muscle Health:** Adequate calcium and vitamin D intake is crucial for maintaining bone density and preventing osteoporosis. Additionally, sufficient protein intake helps prevent muscle loss, reducing the risk of frailty and falls. These are vital nutritional requirements for elderly people (Paddon-Jones & Rasmussen, 2009; Weaver et al., 2016; Bauer et al., 2013).
- **Energy and Vitality:** A healthy diet for senior citizens ensures the body has the energy needed for daily activities, helping seniors stay active. Foods rich in whole grains, lean proteins, and healthy fats can boost energy and vitality (Roberts & Rosenberg, 2006).
- **Improved Immune Function:** Proper nutrition strengthens the immune system, enabling the elderly to fight infections and illnesses more effectively. Nutrients like vitamins A, C, and E and zinc play a critical role in immune function (Chandra, 2002).
- **Better Mental Health:** Good nutrition can enhance mental well-being and reduce the risk of depression and anxiety. The social aspects of eating, such as sharing meals with others, can also positively impact mood and mental outlook (Locher et al., 2005; Akbaraly et al., 2009).

Conclusion:

Geriatric nutrition is not just about giving food—it is about making sure that older adults receive the right kind of food that supports their health, independence, and happiness. Eating in later life should not only meet basic nutritional needs but also bring comfort, enjoyment, and dignity.

For seniors, food acts like medicine, because it can help prevent or manage health conditions such as diabetes, high blood pressure, osteoporosis, and memory decline. Choosing nutrient-dense foods (like fruits, vegetables, whole grains, lean proteins, dairy alternatives, and healthy fats) ensures that even if appetite or food intake decreases, the body still gets essential vitamins, minerals, and energy (de Groot & van Staveren, 2002; Milne et al., 2009).

Equally important is how food is prepared and presented. Meals should be easy to chew, swallow, and digest, while still tasting good and looking appealing. Small adjustments—like using softer textures, stronger flavors, or fortified foods—can make eating more enjoyable and effective for seniors (Cichero, 2013; Kremer et al., 2007).

The eating environment also matters. Eating with family, friends, or in a calm, pleasant setting can reduce loneliness, improve appetite, and encourage better nutrition. Caregivers and family members play a vital role in this process by planning balanced meals, respecting cultural food preferences, and creating positive mealtime experiences (Locher et al., 2005).

Ultimately, good nutrition in older age helps maintain strength, mobility, mental clarity, and quality of life. When food is treated as both nourishment and enjoyment, the later years of life can truly be healthy, vibrant, and fulfilling (Brownie, 2006).

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Mapping Tribal Turmeric Farmer Producer Organizations in Andhra Pradesh: Action Plan and Institutional Interventions

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Turmeric transcends its role as a mere spice in the tribal areas of Andhra Pradesh; it embodies the core of livelihood and cultural identity. Nevertheless, many tribal cultivators persist in selling raw and unpolished rhizomes to village traders, often at very low profit margins. Farmer Producer Organizations (FPOs) possess the capacity to alter this situation by consolidating produce, enhancing value, and negotiating more effectively. FPOs present a transformative opportunity to break free from this cycle. By pooling resources and consolidating their output, FPOs empower tribal farmers to transition from being passive price-takers to proactive market participants. Through collective strength, they can secure better prices, mitigate exploitation by intermediaries, and venture into new markets beyond local traders. More crucially, FPOs facilitate value addition such as grading, curing, polishing, packaging, branding, and even exploring export opportunities all of which can substantially boost the incomes of tribal farming communities. To realize this potential, comprehensive mapping of turmeric-based FPOs and their action plan is essential, alongside targeted interventions from institutions tailored to tribal context, particularly in the Alluri Sitharama Raju (ASR) district of Andhra Pradesh.

Turmeric Area and Production in ASR District

Turmeric cultivation within ASR district reveals considerable variability in both area and production across the district (Table 1). Turmeric is cultivated across 21,987 acres in the tribal mandals, yielding a total production of 24,762.25 metric tonnes (Mt). The average productivity works out to about 1.13 Mt per acre, indicating fairly consistent yields across the region. G. Madugula mandal ranks highest, with 4,657 acres under turmeric cultivation and a production of 5,608.63 MT followed by Chintapalli (5043.5 MT) and Peda Bayalu (4056.25 MT). In these major turmeric-producing mandals, several turmeric-based FPOs have been in operation to promote collective marketing, value addition, and enhanced income for tribal farmers. During 2024-25, survey data collected from the ASR District Horticulture Department and Integrated Tribal Development Agency data base, reported a total of 59 FPOs in the district, of which 25 (42%) were turmeric-based. These FPOs are primarily located in G. Madugula, Chintapalli, Peda Bayalu, G.K. Veedhi, and Paderu where turmeric cultivation is majorly concentrated. They play a pivotal role in aggregating produce, facilitating access to input and output markets, and promoting primary processing and branding initiatives. The convergence of high turmeric production and the presence of functional FPOs in these mandals provide a strong foundation for developing sustainable turmeric value chains in ASR district.

Table 1: Mandal wise Turmeric Area and Production statistics in ASR district

Mandal	Area (Acres)	Production (Mt)
Munchingi Puttu	1415	1556.5
Dumbriguda	1165	1281.5
Araku Valley	112	123.75
Koyyuru	80	88
Paderu	1833	2106.37
G. Madugula	4657	5608.63
G.K.Veedhi	2575	2832.5
Chintapalli	4585	5043.5
Peda Bayalu	3688	4056.25
Hukumpeta	1828	2010.25
Y. Ramavaram	50	55
Total	**21987**	**24762.25**

Source: Horticulture Department, ASR district, 2024-25

Turmeric-based FPOs in ASR District

The mapping of Farmer Producer Organizations in the tribal belt of Alluri Sitharama Raju district reveals clear patterns in terms of institutional involvement and geographical spread. Non-Government Organizations (NGO) like GVSSS, Kovel Foundation, Jagruthi Macts, Smile Welfare Society, BREDS, CSA, and Giri Chaitanya are playing a crucial role as promoting institutions. Further, Department of Horticulture and District Rural Development Agency (DRDA) together account for 10 FPOs, indicating strong government-backed institutional presence in the region. The support also rendered by ICAR institutes showing a healthy mix of government, research, and NGO involvement. Paderu, Chintapalli, G.K. Veedhi, G. Madugula mandals and Hukumpeta host the highest number of turmeric-based FPOs, making them natural cluster hubs for targeted interventions. Dumbriguda, Araku, Munchingiputtu, and Pedabayalu have relatively fewer FPOs, suggesting a need for scaling up and providing additional institutional support in these regions.

Table 2: Mapping of Turmeric-based FPOs in ASR District

S.N	Name of FPO Promoting Institute	Name of FPO	Mandal
1.	Girijana Vikas Swatchanda Seva Samstha (GVSSS)	Maathota Tribal Farming & Marketing Producers Company ltd.	GK Veedhi
2.	Kovel Foundation	M Nittaputtu Girijana Rythu seva mariyu vutpattidarula MACS	Paderu
3.	JAGRUTHI MACTS	Vanaphala FPO	Hukumpeta
4.	Girijana Vikas Swatchanda Seva Samstha (GVSSS)	Gantannadora FPO	Chintapalli
5.	Girijana Vikas Swatchanda Seva Samstha (GVSSS)	Maanyatorana Farmer Producer Com. Ltd.	Paderu
6.	Smile Welfare Society	Vaisakhi Siridhanyalu FPO	Paderu
7.	BREDS	Arunatara FPC Ltd	GK Veedhi
8.	BREDS	Sagara Mouli Araku Dumbriguda FPC Ltd	Araku, Dumbriguda
9.	BREDS	Sugamana FPC Ltd	Chintapalli
10.	Centre for Sustainable Agriculture (CSA)	Girisiri FPC Ltd	G Madugula
11.	Indian Institute of Millet Research (IIMR)	Lambasingi Tribal FPC Ltd	Chintapalli
12.	IIMR	Girisiri Tribal FPC MACTS Ltd	Paderu
13.	IIMR	FPO	Hukumpeta
14.	IIMR	FPO	G Madugula
15.	Giri chaitanya NGO, GK Veedhi	Giri Chaitanya Farming and Marketing Mutually Aided Cooperative Society Ltd	GK Veedhi
16.	Department of Horticulture	Andhra Kaashmir Tribal farming & marketing producer company	Chintapalli
17.	Department of Horticulture	DIMSA FPCL	Chintapalli
18.	Department of Horticulture	Jai Kisan Udyana Mairyu Vyavasaya anubhandha utpatthidarula paraspara sahayaka sahakara sangham Ltd.	Munchingi Puttu
19.	Department of Horticulture	Giriputrula Udyana Mairyu Vyavasaya anubhandha utpatthidarula paraspara sahayaka sahakara sangham Ltd.	Dumbriguda
20.	District Rural Development Agency (DRDA)	The Chinthapalli Agriculture and Allied Producers Mutually Aided Cooperative Society Ltd	Chinthapalle
21.	District Rural Development Agency (DRDA)	The G Madugula Agriculture and Allied Producers Mutually Aided Cooperative Society Ltd	Gangaraju Madugula
22.	District Rural Development Agency (DRDA)	The G K Veedhi Agriculture and Allied Producers Mutually Aided Cooperative Society Ltd	G K Veedhi
23.	District Rural Development Agency (DRDA)	The Munchingiputtu Agriculture and Allied Producers Mutually Aided Cooperative Society Ltd	Munchingiputtu
24.	District Rural Development Agency (DRDA)	The Paderu Agriculture and Allied Producers Mutually Aided Cooperative Society Ltd	Paderu
25.	District Rural Development Agency (DRDA)	The Pedabayalu Agriculture and Allied Producers Mutually Aided Cooperative Society Ltd	Pedabayalu

Action Plan of Turmeric-Based FPOs

The existing action plan of FPOs emphasizes training, collective action, processing, branding, and sustainable practices, with institutional and financial support.

1. **Advocating for Good Agricultural Practices (GAP) and Organic Certification:** Promoting GAP ensures sustainable and environmentally sound cultivation. Encouraging organic certification through department of horticulture enhances the market value, enabling access to premium domestic and export markets for chemical-free turmeric.
2. **Linkage with NABARD and Spice Board for subsidies and financial support :** NABARD and the Spice Board Field Office at Paderu mandal is encouraging targeted schemes for value chain strengthening, post-harvest processing, and export promotion of spices. FPOs are leverage these through regular rapport by submitting proposals for infrastructure development such as steam boilers, dryers and polishers, and for capacity-building programmes. Institutional linkage of FPOs also enables access to soft loans, credit guarantees, and subsidy components under FPO and spice cluster development programs.
3. **Collective procurement of inputs at subsidized rates:** This collective approach of FPOs ensures quality assurance, timely availability, and reduction in per-unit cost, thereby enhancing productivity and profitability.
4. **Facilitating short term credit through pre-agreement with traders and cooperative banks:** Access to working capital is crucial for smallholders. FPOs are negotiating pre-harvest credit lines with cooperative banks, Primary Agricultural Cooperative Societies (PACS), and private traders based on collective agreements. This facilitates crop investment and prevents distress sales.
5. **Training of FPO personnel**: Professionalization of FPO management is vital for sustainability. Regular capacity-building to Board of Directors and CEOs in record-keeping, business planning, and compliance builds managerial competence and transparency.
6. **Strengthening governance**: Institutional credibility depends on good governance. FPOs are ensuring periodic board meetings, member participation in Annual General Meetings (AGMs), and transparent financial audits.
7. **Collective aggregation**: By aggregating turmeric produce at the FPO level, farmers are achieving scale advantages and negotiating better prices with bulk buyers and processors. Establishing common collection centers reduces transportation costs, minimizes trader dependency, of turmeric produce to ensure better bargaining power and reduction in middlemen margins.
8. **Branding of produce**: FPOs are developing a distinct brand identity featuring FPO logo and local cultural symbols to enhance consumer appeal, trust building and product traceability to penetrate niche and tourist places.
9. **Establishing tie-ups with TRIFED and direct buyers:** Strategic partnerships with TRIFED, organic retail chains, exporters, and institutional buyers opens assured market channels for FPOs. TRIFED's procurement system for tribal produce and value-added goods provides stable pricing, while direct tie-ups with government undertaking, Girijan Cooperative Corporation and spice exporters eliminate intermediaries, ensuring higher margins and consistent demand.
10. **Market Expansion through Trade Fairs and Buyer–Seller Meets:** Participation of FPOs in district, state level and national exhibitions, trade fairs, and buyer–seller meets offering an excellent platform for turmeric-based Farmer Producer Organizations to showcase their products, network with potential buyers, which establishes long-term business relationships.

Institute interventions in fostering FPOs

A. Capacity Building and Human Resource Development

Institutes are crucial in improving the managerial and entrepreneurial skills of FPO stakeholders through,

- Training programmes focused on governance, leadership, record keeping, and compliance contribute to the establishment of transparent and accountable frameworks.
- Entrepreneurial skill development to farmers shifts from subsistence farming to market-driven agribusinesses by giving technical guidance through establishing small-scale processing units
- Exposure visits and participatory learning methods enhance peer-to-peer learning and foster confidence among FPO members.

B. Technical Backstopping and Research Support

Research and extension institutions play a vital role in connecting lab research with practical field application, ensuring that FPOs stay competitive through,

- Production technologies: Institutions disseminate improved varieties, integrated pest management strategies, and Good Agricultural Practices
- Post-harvest and processing: Assistance in grading, packaging, branding, and certification increases market value
- Digital innovations: Precision agriculture tools, mobile-based advisories, e-market platforms enhances efficiency

C. Market Linkages and Value Chain Development

The sustainability of FPOs is significantly influenced by their capacity to integrate into profitable markets by,

- Facilitating direct connections with processors, exporters, and institutional buyers.
- Aiding in the establishment of commodity clusters to bolster bargaining power.
- Assisting in the creation of brands, GI-based marketing strategies, attractive packing, labelling and collective trademarks to improve visibility and foster consumer trust.

D. Financial Facilitation and Institutional Support

Access to credit continues to be a significant obstacle for FPOs. Institutions take action by:

- Assistance in development of viable business plans and projects
- Providing equity grants, credit guarantees, and subsidies through the programmes of NABARD, SFAC, and state governments.
- Connecting FPOs with venture capital and private investments to aid in their expansion.

E. Policy Advocacy and Convergence

Institutes act as knowledge partners to governments in formulating policies of,

- Guarantee the involvement of women and all the tribal communities, and marginalized groups.
- Encourage collaboration among line departments, NGOs, and private stakeholders to provide integrated support.
- Create cluster-based development models that are in harmony with national priorities

F. Monitoring, Evaluation, and Impact Assessment

Institutes play a vital role in monitoring and assessing the performance of FPOs.

- Key indicators, including membership growth, turnover, profitability, and sustainability, are evaluated on a regular basis.
- Research outcomes deliver evidence-based insights for policymakers and funding organizations.
- Impact assessments showcase both achievements and obstacles, providing valuable lessons for expansion.

Conclusion

Turmeric-based farmer producer organizations located in the tribal heartland of Andhra Pradesh, especially within the ASR district, serve as a significant avenue for converting subsistence farming into a sustainable, market-oriented business. By utilizing institutional support, enhancing value, and engaging in collective bargaining, these organizations can achieve increased incomes, lessen reliance on intermediaries, and establish a more robust position for tribal farmers in both national and international markets. With appropriate policy backing, financial assistance, and skill development, turmeric FPOs possess the capability not only to bolster rural livelihoods but also to maintain the cultural heritage of tribal communities while incorporating them into resilient and fair value chains.

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HUMAN-A FACTOR IN CLIMATE CHANGE

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Climate change is a pressing global issue with far-reaching consequences for the environment, ecosystems, and human society. As we are aware about the changing of climate overally everyday;so in this context the humans hold a major part directly or indirectly related to climate change.

Human activities play a significant role in exacerbating climate change. From burning fossil fuels to deforestation, the choices we make have far-reaching consequences. It could be observed that the environment is being totally changes due to the negative impact of human beings.For our benefit we vigorously kept on changing the beauty and cycle of climate.

This article explores the significant role of human beings in climate change and the consequences of our actions.

The Greenhouse Effect:

The greenhouse effect is a crucial mechanism that regulates the Earth's temperature. Natural greenhouse gases, such as water vapour and carbon dioxide, trap heat from the sun, keeping the planet warm enough to sustain life. However human activities such as burining of fossil fuels,deforestation,etc are significantly increasing the concentration of greenhouse effect.

Emissions from Fossil Fuels:

The combustion of fossil fuels, like coal, oil, and natural gas, is the largest contributor to greenhouse gases. These activities release carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O) into the atmosphere.

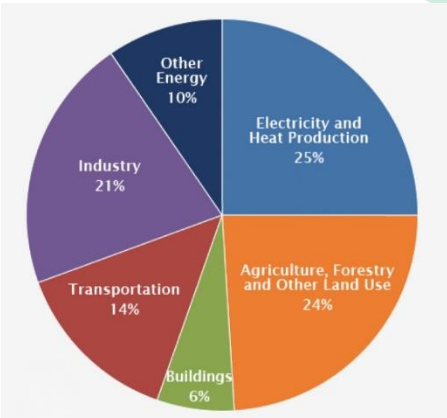
Deforestation:

Deforestation is another human-induced factor contributing to climate change. Cutting of trees recklessly at a high rate leads to deforestation which is causes a large factor in climatic change.

Anthropogenic Activities Contributing to Climate Change

- Fossil fuel combustion for electricity and transportation is a major contributor to greenhouse gas emissions.
- The destruction of forests reduces the planet’s capacity to absorb carbon dioxide and disrupts ecosystems.
- Industrial activities release greenhouse gases and other pollutants into the atmosphere.
- Disturbance occurring due to marine such as floods, tsunami, cyclone also disturbs the climate.

Greenhouse Gases Emissiom due to Economic Sector:



Human beings play a defining role in climate change, both as contributors and change makers. By understanding the consequences of our actions and taking responsibility, we can work towards a sustainable future. Let us unite to address the challenges of climate change and preserve the planet for generations to come.

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Innovative Approaches for Development of Farmers-Friendly Fodder Densification, Preservation and Quality Improvement Technologies

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Introduction

Livestock represents an essential component of rural economies, especially in many developing countries, by offering income, nutritional security, employment and a buffer against agricultural risks. However, one of the major constraints that smallholder livestock farmers face is the seasonal shortage of good quality fodder, which leads to decreased animal productivity in terms of milk yield, growth, reproduction and health. The bulk, moisture variability, perishability and low nutritive value of many local feed resources compound this problem.
Livestock production plays a crucial role in the livelihood security of millions of farmers worldwide, particularly in developing countries where mixed crop-livestock farming is predominant. India, for instance, sustains the world's largest livestock population with nearly 536 million heads as per the 20th livestock census. Livestock contributes significantly to agricultural GDP, nutrition, employment and women empowerment in rural areas. However, one of the most pressing challenges faced by farmers is the availability of quality fodder throughout the year.

Good quality fodder scarcity, seasonal fluctuations in biomass availability and poor nutritive quality of conventional feed resources adversely affects animal productivity. Studies indicate that India faces an estimated green fodder deficit of 35-40% and a dry fodder deficit of 25-30%. The problem intensifies during lean periods (summer and late winter), droughts or floods, when green fodder availability drastically declines. To address this gap, innovative, farmer-friendly technologies for fodder preservation, densification and quality enhancement are essential. Such approaches not only ensure round-the-year feed availability but also reduce wastage, improve feed efficiency, minimize transportation costs and enhance the overall economic returns from livestock.
To overcome these constraints, there is growing interest in technologies for fodder preservation, densification and quality enhancement that are farmer-friendly, cost-effective and adaptable to varied agro-ecological zones. Therefore, this paper elaborates on the innovative strategies, emerging technologies, practical interventions and future directions for developing fodder management systems that are both sustainable and accessible to smallholder farmers.

Need for innovation

Fodder availability fluctuates with seasons: abundant during monsoons or harvest periods, but scarce in dry or lean seasons. Green fodder deteriorates quickly after cutting due to microbial and enzymatic activity, while dry fodder and crop residues often have low digestibility and protein content. The transportation and storage of bulky and moist fodder also increase costs and losses. Hence, preserving fodder (e.g., via silage or hay), densifying it (into blocks, pellets, or bales) and enhancing its quality (nutrient content, digestibility, palatability) are vital to stabilizing livestock feed supply. For smallholder farmers, methods must be simple, affordable, low-energy and resilient to local constraints.

Key dimensions

1. Preservation refers to techniques that retard spoilage and nutrient losses. Traditional methods include haymaking and ensiling. Innovations in preservation aim to reduce drying time, improve fermentation and minimize losses under adverse weather.
2. Densification involves converting bulky and loose biomass into compact form bales, blocks, pellets to ease handling, transportation, storage and to improve feeding efficiency.

3. Quality Enhancement comprises improving the feed's nutritional profile (protein, minerals), reducing anti-nutritional or toxic factors, improving digestibility and addressing physical factors (moisture, particle size) that affect intake and animal health.

Recent innovations and research

Recent agronomic and technological innovations have begun to meet these needs:

Integrated soil fertility and nutrient management strategies are being used to improve fodder yield and quality. For example, use of bio-fertilizers or plant growth promoting rhizobacteria (PGPR), organic amendments, foliar sprays (e.g., Panchagavya), along with reduced chemical fertilizer doses have shown significant improvements in crude protein, reduced fibre fractions, enhanced dry matter digestibility in fodder maize, berseem and cowpea etc. Micronutrient biofortification, e.g., application of zinc and iron fertilization in berseem or iron chelates in sorghum, has been shown to improve both yield and nutritive parameters while reducing undesirable compounds (e.g., cyanogens) in fodder crops. Use of saline or marginal water with strategic leaching fractions has enabled growth of high-quality alfalfa fodder in arid soils, opening up possibilities for fodder production where freshwater is limited.

Agronomic improvements in seed rate, timing of sowing and harvesting (cutting), intercropping (legume + cereal mixes) and weed/insect management have been identified as strong levers to enhance both fodder yield and quality metrics such as crude protein, digestibility etc. On the preservation side, silage making is being increasingly promoted not just as a feeding strategy but also as a potential entrepreneurial activity among farmers. Demonstration projects in India show farmers in certain regions adopting silage for lean season feed, guided by technological training and expert advice.

Institutional innovations: national and state fodder development schemes aim to combine technological advances (e.g. hydroponics, silvipastoral systems), seed production of improved fodder species, demonstration units, and subsidy or procurement support in order to scale up farmer adoption.

Farmer-friendly aspects

For innovations to be adopted widely by smallholder farmers, certain criteria are critical:

Low cost: Both in capital (machinery and infrastructure) and operational (inputs and labour).

Local adaptability: Technologies suited to local feed resources (crop residues, grass and legumes), local climate and water availability.

Ease of operation: Minimal technical skill, strong extension support.

Modularity and scalability: Able to work at small scale, community level or larger scale depending on resources.

Multi-benefits: Improved animal productivity, reduced feed cost, reduced losses, environmental sustainability (e.g., efficient use of resources, reduced wastage).

The promise of integrated approaches

The convergence of agronomic, biological, chemical and engineering solutions opens up integrated pathways. For example, combining improved fodder varieties, micronutrient enrichment, followed by preservation (ensiling or haymaking) and densification (block or pellet making) can lead to feed that is available year round, has high nutritive value, is easier to store/transport and is more cost effective. Digital tools, community organizations (farmer producer organizations, fodder banks) and policy support play synergistic roles in ensuring widespread adoption.

Scope of this paper

This paper will explore the state-of-the-art and emerging technologies in fodder preservation, densification and quality enhancement, with a focus on those that are farmers-friendly. It will consider agronomic innovations, engineering/processing technologies, socio-institutional models, economic viability and constraints to adoption and future directions. The goal is to provide a perspective on how to develop and implement technologies that are practical and sustainable at the smallholder farmer level.

Importance of fodder preservation and quality enhancement

Role of fodder in livestock productivity

Provides energy, protein, vitamins and minerals,

Ensures rumen health through balanced roughage-concentrate ratio,

Reduces dependence on expensive concentrate feeds, Enhances milk yield, reproductive efficiency and draft power,

Challenges in fodder availability

Fragmented landholdings restrict dedicated fodder cultivation,
Overdependence on rain-fed fodder crops,
Post-harvest losses due to lack of preservation technologies,
Poor adoption of improved fodder varieties,
Transport and storage challenges due to bulkiness of fodder,

Why preservation and densification of fodder?

Preservation: Helps extend shelf life, ensures feed supply in lean seasons and minimizes spoilage.
Densification: Converts bulky biomass into compact, easy-to-handle and transportable forms such as pellets or blocks.
Quality Enhancement: Improves digestibility, palatability and nutrient profile of low-quality crop residues.

Traditional methods of fodder preservation

Before diving into innovative approaches, it is essential to understand the conventional practices farmers have been using for centuries.

Haymaking

Sun-drying green fodder until moisture reduces to about 15%. It is simple and low-cost method,
Limitations: Weather-dependent, nutrient losses (leaf shattering and vitamin degradation).

Silage making

Fermentation of green fodder under anaerobic conditions,
Preserves nutrients and enhances palatability,
Limitations: Requires airtight structures, skill in harvesting at proper stage and ensiling techniques.

Drying of crop residues

Farmers traditionally store crop residues like wheat straw, paddy straw and maize stover.
Provides bulk but nutritionally poor.
While these methods form the backbone of fodder preservation, they need technological refinement to make them more efficient, less labor-intensive and adaptable to smallholder conditions.

Innovative approaches in fodder preservation

Improved silage technologies

Baled silage: Packing chopped fodder into plastic-wrapped bales (mini silage bags of 25–50 kg). It is highly suitable for smallholders.
Silage inoculants: Lactic acid bacteria inoculants enhance fermentation quality, reduce spoilage and preserve nutrients.
Community silage units: Shared infrastructure at village or FPO level for cost-effective silage production.
Underground bag silage: Low-cost polyethylene tube silage pits requiring minimal investment.

Low-cost haymaking innovations

Solar hay dryers: Reduce drying time and prevent nutrient losses due to rains.
Chaffed hay storage: Chaffing before storage increases density, reduces storage volume and improves handling.
Improved hay baling machines: Small-scale, tractor-operated or manual balers for smallholder use.

Crop residue preservation

Urea-ammoniation technology: Treating straw with 3–4% urea solution enhances crude protein content by 2–3 times and improves digestibility.
Urea-molasses treatment: Boosts energy content and palatability.
Fungal treatment (Biological up-gradation): White-rot fungi degrade lignin, making fibrous residues more digestible.

Fodder densification technologies

Complete feed blocks (CFBs)

A balanced mixture of crop residues, concentrates, molasses, urea and minerals compacted into blocks.
Advantages: Reduces selective feeding, increases nutrient use efficiency and facilitates storage/transport.
Innovations: Portable manual block-making machines for village use.

Pelleting technology

Crop residues and feed ingredients are processed into pellets.

Benefits: Increases bulk density, enhances digestibility, reduces transportation cost and ensures balanced nutrition.

Innovations: Solar-powered small pelletizers for rural areas.

Baling

Compressing fodder into bales (rectangular or round),

Reduces transportation costs by 60–70%,

Adoption of mini-balers for small farms is increasing,

Quality enhancement technologies

Chemical treatments

Urea/ammonia treatment: Enhances protein and digestibility of straw.

Lime or alkali treatment: Breaks lignocellulosic bonds in residues.

Molasses enrichment: Improves energy content and palatability.

Biological treatments

Fungal inoculation: White-rot fungi reduce lignin content.

Probiotic fortification: Improves rumen microbial activity and feed utilization.

Nutrient fortification

Mineral mixtures and bypass nutrients: Incorporation during densification ensures balanced rations.

Protein-energy blocks: Provide a balanced supplement for ruminants during drought.

Digital and smart innovations

ICT and mobile apps

Mobile apps to guide farmers on silage preparation, fodder harvesting stage, urea treatment protocols and weather-based advisory.

IoT-enabled storage structures

Smart silos equipped with sensors for temperature, humidity and pH monitoring,

Early detection of spoilage or fungal growth,

Drone-assisted fodder mapping

Identify fodder availability across regions for community-based fodder banks.

Fodder supply chain platforms

Digital platforms connecting fodder producers with buyers, reducing wastage and ensuring year-round supply.

Farmer-friendly models

Community fodder banks

Cooperative approach for storing preserved fodder at village level,

Works as a buffer stock during droughts or lean seasons,

Farmer producer organizations (FPOs)

Collective fodder processing (silage, pellets, blocks) at community units,

Increases bargaining power and reduces per-unit processing costs,

Custom hiring centres

Renting balers, chaff cutters and block-making machines at affordable rates,

Ensures accessibility to small and marginal farmers,

Case studies of innovative fodder management

Mini silage bags in Punjab

Farmers successfully adopted 25–30 kg silage bags, reducing fodder wastage and ensuring year-round dairy feed supply.

Crop residue pellets in Karnataka

Conversion of maize stover and groundnut haulms into pellets reduced fodder scarcity in dry zones.

Community hay-baling in Rajasthan

Self-help groups baled surplus bajra stover during harvest and stored it in village fodder banks for use during drought.

Policy support and institutional innovations

Government schemes: National livestock mission (NLM), rashtriya gokul mission (RGM) promoting fodder cultivation and conservation.

Public-private partnerships: Engaging agribusiness firms in silage marketing.

Research-extension linkages: Translating lab innovations into farmer-friendly technologies.

Challenges in adoption

Limited awareness among farmers,
High initial cost of machines (pelletizers and balers, etc.),
Lack of extension support in remote areas,
Storage and packaging challenges,
Market linkages for processed fodder not well established,

Future roadmap

Research priorities

Development of low-cost, solar-powered fodder processing machines,
Genetic improvement of fodder crops with higher nutritive value and better preservation traits,
Nano-mineral fortification for improved bioavailability,

Extension and capacity building

Farmer training programs on silage, haymaking, and crop residue management,
Demonstration units in every block for hands-on learning,

Sustainable and climate-resilient approaches

Drought-tolerant fodder varieties,
Agroforestry-based fodder production systems,
Circular bio-economy approaches (using crop residues efficiently),

Conclusion

Fodder scarcity remains a formidable challenge to livestock productivity, particularly in smallholder systems. Traditional methods like silage and haymaking are valuable but need technological innovations to make them efficient, scalable and farmer-friendly. Emerging approaches such as mini silage bags, crop residue densification, urea treatment, feed blocks and ICT-based advisory systems are transforming the way farmers manage livestock feed. Densification technologies like pelleting and block-making not only reduce transport costs but also enable balanced rations. Biological and chemical treatments add to quality enhancement, while community fodder banks and FPO models ensure accessibility and sustainability. With policy support, capacity building and research breakthroughs, it is possible to ensure year-round availability of quality fodder, thereby strengthening the livestock sector, improving rural incomes and contributing to national food and nutritional security.

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Conservation Agriculture

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Abstract

There is an urgent need to match food production with increasing world population through identification of sustainable land management strategies. However, the struggle to achieve food security should be carried out keeping in mind the soil where the crops are grown and the environment in which the living things survive. Conservation agriculture practices—no-till in particular—have been promoted for their potential to mitigate climate change. The potential for no-till alone to mitigate climate change by sequestering carbon may be less than previously thought, but other aspects of CA have mitigation potential. Conservation agriculture (CA) technologies involve minimum soil disturbance, permanent soil cover through crop residues or cover crops, and crop rotations for achieving higher productivity. The technologies of CA provide opportunities to reduce the cost of production, save water and nutrients, increase yields, increase crop diversification, improve efficient use of resources, and benefit the environment. However, there are still constraints for promotion of CA technologies, such as lack of appropriate seeders especially for small and medium scale farmers, competition of crop residues between CA use and livestock feeding, burning of crop residues, availability of skilled and scientific manpower and overcoming the bias or mindset about tillage. Processes of climate change mitigation and adaptation found zero tillage (ZT) to be the most environmental friendly among different tillage techniques. Therefore, conservation tillage involving ZT and minimum tillage which has potential to break the surface compact zone in soil with reduced soil disturbance offers to lead to a better soil environment and crop yield with minimal impact on the environment.

Keywords

Atmosphere, Greenhouse gases Conservation tillage Sustainable crop yield

Introduction

Attaining food security for a growing population and alleviating poverty while sustaining agricultural systems under the current scenario of depleting natural resources, negative impacts of climatic variability, spiraling cost of inputs and volatile food prices are the major challenges before most of the Asian countries. In addition to these challenges, the principal indicators of non-sustainability of agricultural systems includes: soil erosion, soil organic matter decline, salinization. These are caused mainly by: (i) intensive tillage induced soil organic matter decline, soil structural degradation, water and wind erosion, reduced water infiltration rates, surface sealing and crusting, soil compaction, (ii) insufficient return of organic material, and (iii) monocropping. Therefore, a paradigm shift in farming practices through eliminating unsustainable parts of conventional agriculture (ploughing/tilling the soil, removing all organic material, monoculture) is crucial for future productivity gains while sustaining the natural resources.

Conservation agriculture (CA) is a sustainable farming system focused on minimizing soil disturbance, maintaining a permanent soil cover, and diversifying crop species. It aims to enhance soil health, improve water and nutrient use efficiency, and increase crop yields while reducing the negative environmental impacts of agriculture.

CA is a resource-saving agricultural production system that aims to achieve production intensification and high yields while enhancing the natural resource base through compliance with three interrelated principles, along with other good production practices of plant nutrition and pest management. Traditional agriculture, based on tillage and being highly mechanized, has been accused of being responsible for soil erosion problems, surface and underground water pollution, and more water consumption. Moreover, it is implicated in land resource degradation, wildlife and biodiversity reduction, low energy efficiency and contribution to global warming problems. Hence, conservation agriculture (CA) is a way to cultivate annual and perennial crops, based on no vertical perturbation of soil (zero and conservation tillage), with crop residue management and cover crops, in order to offer a permanent soil cover and a natural increase of organic matter content in surface horizons. The main environmental consequences of this method have been investigated worldwide with the objective of presenting a synthesis of the available studies and documents to the farmers and scientific communities. It stresses the very beneficial impacts of a conservative way of cultivation on the global environment (soil, air, water and biodiversity), compared to traditional agriculture. Further, it also presents the actual gaps or uncertainties concerning the scientists' positions on these environmental aspects. CA promotes most soils to have a richer bioactivity and biodiversity, a better structure and cohesion, and a very high natural physical protection against weather (raindrops, wind, dry or wet periods). Soil erosion is therefore highly reduced, soil agronomic inputs transport slightly reduced, while pesticide bio-degradation is enhanced. It protects surface and ground water resources from pollution and also mitigates negative climate effects. Hence, CA provides excellent soil fertility and also saves money, time and fossil-fuel. It is an efficient alternative to traditional agriculture, attenuating its drawback. This paper aims to advantages and methods of conservation tillage in agro-ecological regions so as to understand its impact from the perspectives of the soil, the crop and the environment.

Principles of conservation agriculture

Adoption of CA for enhancing Resource use efficiency (RUE) and crop productivity is the need of the hour as a powerful tool for management of natural resources and to achieve sustainability in agriculture. Conservation agriculture basically relies on 3 principles, which are linked and must be considered together for appropriate design, planning and implementation processes. These are:

Minimal mechanical soil disturbance

The soil biological activity produces very stable soil aggregates as well as various sizes of pores, allowing air and water infiltration. Minimum soil disturbance provides/maintains optimum proportions of respiration gases in the rooting-zone, moderate organic matter oxidation, porosity for water movement, retention and release and limits the re-exposure of weed seeds and their germination.

Permanent organic soil cover

A permanent soil cover is important to protect the soil against the deleterious effects of exposure to rain and sun; to provide the micro and macro organisms in the soil with a constant supply of "food"; and alter the microclimate in the soil for optimal growth and development of soil organisms, including plant roots. In turn it improves soil aggregation, soil biological activity and soil biodiversity and carbon sequestration.

Diversified crop rotations

The rotation of crops is not only necessary to offer a diverse "diet" to the soil micro organisms, but also for exploring different soil layers for nutrients that have been leached to deeper layers that can be "recycled" by the crops in rotation. Cropping sequence and rotations involving legumes helps in minimal rates of build-up of population of pest species, through life cycle disruption, biological nitrogen fixation, control of off-site pollution and enhancing biodiversity.

Types of CT

Conservation tillage (CT) is defined as a set of practices aimed at reducing runoff and erosion by maintaining plant residues on at least 30% of the soil surface after tillage. This includes methods such as no-till, strip-till, ridge-till, and mulch-till, which can effectively decrease the loss of particulate phosphorus (P) by erosion.

Prospects of conservation agriculture

(i) Reduction in cost of production –Cost reduction is attributed to savings on account of diesel, labour and input costs, particularly herbicides.

(ii) Reduced incidence of weeds – Most studies tend to indicate reduced incidence of Phalaris minor, a major weed in wheat, when zero-tillage is adopted resulting in reduced in use of herbicides.

(iii) Saving in water and nutrients –Higher soil water content under no-till than under conventional tillage indicated the reduced water evaporation during the preceding period.

(iv) Increased yields –CA has been reported to enhance the yield level of crops due to associated effects like prevention of soil degradation, improved soil fertility, improved soil moisture regime (due to increased rain water infiltration, water holding capacity and reduced evaporation loss) and crop rotational benefits.

(v) Environmental benefits – Conservation agriculture involving zero-till and surface managed crop residue systems are an excellent opportunity to eliminate burning of crop residue which contribute to large amounts of greenhouse gases like CO2, CH4 and N2O. Burning of crop residues, also contribute to considerable loss of plant nutrients, which could be recycled when properly managed. Large scale burning of crop residues is also a serious health hazard.

(vi) Crop diversification opportunities – Adopting Conservation Agriculture systems offers opportunities for crop diversification. Cropping sequences/rotations and agroforestry systems when adopted in appropriate spatial and temporal patterns can further enhance natural ecological processes.

(vii) Resource improvement – No tillage when combined with surface management of crop residues begins the processes whereby slow decomposition of residues results in soil structural improvement and increased recycling and availability of plant nutrients. Surface residues acting as mulch, moderate soil temperatures, reduce evaporation, and improve biological activity.

Constraints for adoption of conservation agriculture

- Lack of appropriate seeders especially for small and medium scale farmers
- The wide spread use of crop residues for livestock feed and fuel
- Burning of crop residues
- Lack of knowledge about the potential of CA to agriculture leaders, extension agents and farmers
- Skilled and scientific manpower

Conclusion

Conservation agriculture offers a new paradigm for agricultural research and development different from the conventional one, which mainly aimed at achieving specific food grains production targets in India. A shift in paradigm has become a necessity in view of widespread problems of resource degradation, which accompanied the past strategies to enhance production with little concern for resource integrity. Integrating concerns of productivity, resource conservation and soil quality and the environment is now fundamental to sustained productivity growth.

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Mechanisms of Sperm Competition and Allocation Trade-Offs in Insects: Strategies Enhancing Reproductive Success

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Abstract

Sperm competition occurs when sperm from multiple males compete to fertilize a female's eggs, triggering diverse adaptations in insects to maximize reproductive success. Key mechanisms involved include sperm removal by mechanical, flushing, and chemical means, sperm stratification within female sperm storage organs, and sperm dilution through large ejaculates. These strategies allow males to increase their chances of fertilization in polyandrous systems. Simultaneously, insects face allocation trade-offs where resources invested in pre-copulatory traits such as mate acquisition and dispersal may reduce investment in post-copulatory traits like sperm production and quality. This review highlights sperm competition mechanisms with examples from damselflies, Drosophila, and leafcutter ants, and discusses allocation trade-offs exemplified by *Solenopsis invicta* and Lepidoptera, emphasizing the evolutionary significance and fitness consequences of these reproductive strategies in insects.

Keywords: Sperm competition, sperm removal, sperm stratification, sperm dilution, allocation trade-off, insect reproduction, post-copulatory sexual selection, Solenopsis invicta, Lepidoptera, Drosophila.

Sperm Competition occurs when the sperm from multiple males compete to fertilize a female's eggs. The main mechanisms involved in this process include sperm removal, stratification of sperm, and sperm dilution.

1. Sperm Removal in Insects

In many insect species, males have evolved specialized strategies to maximize their reproductive success by removing or displacing sperm deposited by previous mates. This behavior ensures that their own sperm has a higher chance of fertilizing the female's eggs and represents a classic example of post-copulatory sexual selection. Sperm removal can occur through mechanical or chemical mechanisms, often involving complex adaptations of male genitalia that allow interaction with the female's sperm storage organs.

1.1 Mechanical Sperm Removal

Mechanical sperm removal involves the physical displacement or extraction of rival sperm from the female's reproductive tract before the male deposits his own sperm. This process requires specialized genital structures that are adapted to reach the female's spermatheca or bursa copulatrix, allowing the male to maximize his fertilization success. Males may use bristles, spines, or other appendages to physically dislodge stored sperm, or in some species, sperm transfer is arranged in a manner that pushes previously stored sperm out of the female's reproductive tract.

Examples of Mechanical Sperm Removal

A well-studied example of mechanical sperm removal is observed in damselflies of the genus *Calopteryx*. Male *Calopteryx* possess penises with specialized brush-like or scoop-like structures that allow them to remove sperm stored from previous mates in the female's spermatheca or bursa copulatrix. After extracting rival sperm, the male deposits his own, thereby significantly increasing his paternity success; in some cases, males can remove up to 90% of sperm from prior matings. Similar adaptations are seen in ground beetles (*Carabus* spp.), where males have hooked or spiny genitalia that facilitate the displacement of previously stored sperm before transferring their own. Another example is found in damselflies of the genus *Lestes*, whose males have distal spines on the penis specifically designed to extract rival sperm from the female's storage organs before insemination.

1.2 Flushing in Insects

Flushing is another strategy employed by males to increase their reproductive success by reducing the presence or effectiveness of sperm from previous mates. In this method, the male first ejaculates a seminal fluid into the female's reproductive tract before transferring his own sperm. This fluid serves to displace, dilute, or otherwise reduce the viability of previously stored sperm, thereby giving the male's sperm a competitive advantage in fertilizing the female's eggs. The mechanism of flushing can involve chemical and physical effects: chemically, certain components of the seminal fluid may incapacitate or immobilize rival sperm, while physically, the fluid volume can push existing sperm out of storage organs such as the spermatheca or bursa copulatrix.

A well-documented example of flushing occurs in Drosophila species, commonly used as a model in reproductive biology studies. In these fruit flies, males transfer seminal fluid containing proteins that not only flush out previously stored sperm but may also alter female physiology to favor the fertilization success of the current male. This ensures that the male's sperm has a higher chance of successful fertilization even when the female has mated previously. The flushing mechanism, therefore, represents an important post-copulatory strategy that complements mechanical sperm removal and highlights the diversity of adaptations males have evolved to enhance their reproductive fitness in species with multiple mating opportunities.

1.3 Chemical Sperm Removal in Insects

In addition to mechanical and flushing strategies, many insect males employ chemical sperm removal, where they transfer biochemical agents in their ejaculate that either deactivate, destroy, or otherwise reduce the effectiveness of rival sperm. This strategy is particularly important in species where sperm competition is intense, often due to limited sperm storage capacity within the female's reproductive tract, such as in social insects or species with multiple mating partners. Chemical sperm removal involves seminal fluid proteins (SFPs) or accessory gland proteins (Acps) that can directly affect the viability, motility, or storage of competing sperm, as well as manipulate female reproductive physiology to favor the current male's sperm.

In leafcutter ants (*Atta colombica*), males produce seminal fluids containing proteases, peptidases, and odorant-binding proteins (OBPs) that act to reduce the viability of sperm from previous matings within the queen's reproductive tract. These proteins may degrade competing sperm membranes or alter the chemical environment of sperm storage organs, thereby giving the male's own sperm a competitive advantage. Similarly, in giant honeybees (*Apis dorsata*), males transfer accessory gland proteins analogous to those found in *Drosophila*. These proteins not only reduce the motility and survival of rival sperm but can also manipulate the female's reproductive physiology to favor sperm from the first mating male, for example, by altering the storage environment in the spermatheca.

In Drosophila melanogaster, seminal fluid proteins play a multifaceted role in post-mating sexual selection. Proteins such as Acp36DE facilitate efficient sperm storage within the female's sperm storage organs, ensuring the current male's sperm are preferentially retained, while the sex peptide (SP) alters female post-mating behavior by reducing her receptivity to further mating, indirectly disadvantaging any subsequent males. Several other accessory gland proteins directly compromise the viability of rival sperm, either by affecting their motility or by chemical disruption within the reproductive tract.

A more extreme example is found in the seed beetle (*Callosobruchus maculatus*), where males produce toxic seminal proteins that reduce the likelihood of female remating and actively diminish the survival of sperm from prior matings. These seminal components, including C-type lectins, trypsin-like serine proteases, and other Acps, can physically damage or incapacitate rival sperm, thereby enhancing the reproductive success of the current male. This demonstrates that chemical sperm removal is not only a mechanism of sperm competition but also a powerful evolutionary strategy for securing paternity in species where females mate with multiple males.

2. **Stratification of Sperm:**

Sperm stratification in insects refers to the spatial arrangement and compartmentalization of sperm from multiple males within female sperm storage organs, such as the spermathecae. This organization enables post-copulatory sexual selection mechanisms, where the order and physical positioning of sperm influence male reproductive success.

2.1 Stratification Mechanisms

- Sperm received during mating is transferred into highly specialized structures in the female reproductive tract that ensure viability and facilitate controlled release for fertilization.
- In species like Lepidoptera (butterflies and moths), the spermatheca stores sperm in distinct layers or compartments, often favoring sperm from the most recent (last male) mating—a phenomenon known as last male precedence.

- In Drosophila melanogaster, sperm from different males occupy separate compartments or layers within the reproductive tract, directly affecting fertilization outcomes.
- The structure of the spermatheca (e.g., compartmentalized reservoirs, ducts, accessory glands) and biochemical interactions between seminal fluid and sperm contribute strongly to stratification.

2.3 Significance in Sexual Selection

- Stratification increases competitive advantage for later-mating males, as their sperm is positioned closer to the site of fertilization, enhancing reproductive success.
- Female insects may also mediate sperm storage dynamics through selective uptake, sperm dumping, or cryptic female choice, thus influencing which sperm is most likely to fertilize eggs.
- This arrangement underscores the importance of sperm competition and post-copulatory sexual selection as significant evolutionary forces in insect reproductive biology.

Examples and Implications

- In Lepidoptera, sperm stratification is well documented, with specialized spermathecal structures maintaining and releasing sperm in a manner that supports last male precedence.
- In Drosophila and certain other Diptera, compartmentalization of sperm is correlated with differences in fertilization success among competing males, and female physiological control further affects sperm use.
- Morphological and physiological adaptations in both the spermatheca and sperm packets (spermatodoses) facilitate these processes across various insect groups.

Sperm stratification within the female reproductive tract represents a critical post-copulatory mechanism, shaping patterns of sexual selection and reproductive success in insects that mate with multiple partners.

3. Sperm Dilution:

Sperm dilution in insects is a strategy where a male increases his chances of fertilization by inseminating the female with a large quantity of sperm, effectively overwhelming or diluting the sperm deposited by previous mates. By flooding the female's sperm storage organs with a high number of sperm, the male boosts the likelihood that his sperm will outcompete rival males' sperm during fertilization.

Mechanism of Sperm Dilution

- Males strategically allocate sperm based on the presence or density of rival males, adjusting ejaculate size to increase fertilization success when there is a high risk of sperm competition.
- In species like the beetle Tribolium castaneum (and closely related Tenebrio molitor), males produce high volumes of sperm and can sense the amount of sperm already stored by females, increasing ejaculate size accordingly to dilute rival sperm in the female's reproductive tract.
- This strategy acts by numeric superiority: a higher quantity of sperm increases the probability of successful fertilization by sheer numbers, diluting the presence of earlier males' sperm.

Examples from Insects

- In Tribolium castaneum and Tenebrio molitor beetles, males adjust sperm output based on chemical cues indicating rival presence and sperm competition risk. High male density prompts males to transfer larger ejaculates to overwhelm rival sperm already stored in the female.
- In Drosophila species, males similarly produce sizable ejaculates, which increases their presence in the female's sperm storage, raising their chances of fertilizing eggs.
- Males may also engage in mate guarding behavior alongside sperm dilution to protect their ejaculate from displacement or inhibition by subsequent males, especially in species with indirect sperm transfer through spermatophores where sperm release is delayed.

Evolutionary and Behavioral Implications

- Sperm dilution is an adaptive reproductive tactic shaped by the intensity of sperm competition. Males invest more sperm when competition is high, balancing the energetic cost of sperm production with reproductive advantage.
- Some insect species integrate sperm dilution with other mechanisms such as spermatophore guarding or strategic copula duration to maximize fertilization success.

- This flexible adjustment enhances male reproductive fitness in polyandrous systems where females mate with multiple partners, making sperm dilution a widespread evolutionary response in insects facing sperm competition.

Advantages of Sperm Competition

- **Increases Male Reproductive Success**: Sperm competition drives males to evolve strategies such as producing higher quality, viable, or more motile sperm, ensuring better chances of fertilizing eggs in polyandrous systems where females mate with multiple males.
- **Stimulates Evolutionary Adaptations**: It promotes the evolution of various adaptations such as last male precedence through sperm stratification, sperm dilution through large ejaculates, and sperm removal or displacement mechanisms, enhancing fertilization success.
- **Enhanced Genetic Diversity**: By encouraging females to mate with multiple males, sperm competition increases offspring genetic diversity, which can improve population resilience and adaptability.
- **Female Benefit via Cryptic Choice**: Females can influence sperm use post-copulation, allowing cryptic female choice that may select genetically superior or more compatible sperm, enhancing offspring fitness.

Disadvantages of Sperm Competition

- **Energetic Costs to Males**: Producing large quantities of sperm or engaging in behaviors like mate guarding is energetically costly, potentially reducing male longevity or future reproductive opportunities.
- **Sexual Conflict and Female Harm**: Intense sperm competition can lead to harmful male adaptations such as toxic seminal proteins or mating plugs that reduce female remating ability but may harm female health or longevity, leading to sexual conflict.
- **Trade-offs in Sperm Traits**: There can be trade-offs between sperm quantity and quality due to limited resources, forcing males to balance the number and viability of sperm, sometimes compromising optimal performance.
- **Increased Male-Male Competition**: Sperm competition can intensify male-male competition not only before copulation but also after, which can result in aggressive behaviors and elevated risks for males.

Allocation Trade-Off in Insects

Allocation trade-offs in insects occur when limited resources must be divided between competing physiological or behavioral traits, affecting reproductive success and survival. These trade-offs often arise between traits enhancing mate acquisition and those improving post-copulatory success, or between flight capacity and fecundity.

General Explanation of Allocation Trade-Off

- Insects have finite resources such as energy, proteins, carbohydrates, and lipids that must be allocated to various life functions.
- Investment in one trait (e.g., powerful flight muscles for dispersal and mate searching) limits resources available for other traits (e.g., sperm production or egg development).
- This balance shapes evolutionary outcomes where insects optimize resource allocation based on ecological pressures like mate competition or environmental conditions.

Examples of Allocation Trade-Off in Insects

1. **Solenopsis invicta (Red Imported Fire Ant)**
    - Males invest heavily in body size and flight musculature to enhance dispersal and mate location during mating flights.
    - This pre-copulatory investment reduces the resources available for sperm production, which may lower sperm quality or quantity, affecting post-copulatory success.
2. **Flight-Fecundity Trade-Off in Lepidoptera (Butterflies and Moths)**
    - Increased allocation to flight muscles and wing size improves pollination efficiency but comes at a cost to reproductive output (fecundity).
    - Conversely, more resources invested in reproduction can reduce flight capacity, impacting mate searching and dispersal.
    - This trade-off affects both insect fitness and plant ecology, mediating linkages between pollination and herbivory.

3. Wing-Polymorphic Insects

- In species with wing polymorphism (some individuals winged, others wingless), winged morphs invest in flight capacities, whereas wingless morphs allocate more to fecundity.
- This results in alternative reproductive and survival strategies shaped by environmental demands.

Significance and Impact

- Allocation trade-offs highlight evolutionary compromises between survival, mate acquisition, and reproductive output.
- They explain variation within populations in reproductive tactics and dispersal abilities.
- Knowledge of these trade-offs informs understanding of insect population dynamics, mating systems, and ecological roles such as pollination or herbivory.

In summary, allocation trade-offs in insects are fundamental resource distribution decisions shaping life-history traits, exemplified by species like Solenopsis invicta and Lepidoptera, where enhanced investment in flight reduces reproductive output or sperm competitiveness.

Conclusion

Sperm competition in insects drives the evolution of complex adaptations to secure fertilization success where females' mate with multiple males. Mechanical and chemical sperm removal, stratification, and dilution of sperm illustrate diverse male strategies to outcompete rivals. These reproductive tactics not only enhance male fitness but also contribute to genetic diversity and evolutionary trajectories within populations. Concurrently, the allocation trade-off between pre- and post-copulatory investments shapes individual reproductive tactics, with males balancing resource use for mate-locating traits versus sperm competitiveness. Understanding these mechanisms contributes critical insights into insect mating systems, sexual selection, and life-history evolution, providing a comprehensive view of reproductive success factors in insects.

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Locust: Biology, Behavior and Management

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Abstract

Locusts are among the most destructive agricultural pests, belonging to the order Orthoptera and family Acrididae. They exhibit phase polymorphism, shifting from a solitary phase to a gregarious phase under specific environmental conditions, leading to the formation of massive swarms that cause severe crop damage. The desert locust (*Schistocerca gregaria*) is the most notorious species, capable of traveling up to 150 km per day and consuming a wide range of crops. Other notable species include the Bombay locust (*Patanga succincta*), migratory locust (*Locusta migratoria*) and red locust (*Nomadacris septemfasciata*), each with distinct breeding patterns and geographical distributions. Locusts are widely distributed across arid and semi-arid regions globally, with major infestations recorded in East Africa, India and Pakistan. The locust life cycle comprises three stages: eggs, nymphs and adults. Females lay up to 500 eggs in multiple pods, which hatch within days to weeks depending on the season. Nymphs develop over 3-8 weeks before maturing into winged adults capable of long-distance flight. Both nymphs and adults are damaging stages, feeding on most vegetation except certain resistant plants. Management involves integrated approaches including cultural methods (deep ploughing, trapping, mechanical crushing), physical methods (sound and vapor heat treatment), biological control (entomopathogenic fungi, natural predators) and chemical control (ULV spraying of insecticides such as chlorpyriphos and fipronil). Effective locust management is critical to safeguarding agricultural productivity and preventing widespread famine.

Keywords: Locusts, Phase polymorphism, Desert locust (*Schistocerca gregaria*), Integrated pest management and Crop damage.

Introduction

Locusts are among the most dangerous agricultural pests. They are a group of short horned grasshoppers belonging to (Order) Orthoptera, (family) Acrididae and are hemimetabolous insects. This group of grasshoppers is known for their unusual ability to alter behavior and feeding patterns when they gather in large numbers, a process influenced by environmental conditions. At the adult stage, gregarious locusts form swarms and travel long distances from one area to another. Among them, the Desert Locusts (*Schistocerca gregaria*) is the most notorious, attacking a wide variety of crops and moving with the wide for up to 150 km in a single day. Due to their polyphagous nature and tendency to form massive swarms during outbreaks, they are regarded as one of the most destructive migratory pests. The most severe outbreaks were in East Africa, India and Pakistan.

Taxonomy and Classification

Kingdom – Animalia
Phylum – Arthropoda
Class - Insecta
Order - Orthoptera
Family – Acrididae

Common Group: Short-horned grasshoppers

❖ **Notable Species**:

1. **Desert locust** (*Schistocerca gregaria*) – most destructive of all locust. Mainly occurs in Pakistan, Rajasthan and Gujarat.
2. **Bombay locust** (*Pantanga succincta*) –Mostly confined to Gujarat and Tamil Nadu.

Its breed during mansoon in the western ghats and has only one breed in a year.

3. **Migratory locust** (*locusta migratoria*) – Mainly occurs in Rajasthan and Gujarat.
   Its breed twice in a year: winter-spring breeding occurs in Pakistan and summer-monsoon breeding in Rajasthan and Gujarat. It may have many breeds a year.
4. **Red locust** (*nomadacris septemfasciata*) – present in Africa.

❖ **Phase polymorphism: -**

Feature	Solitary phase	Gregarious phase
Color	Green as of vegetation on which they live, no black marking.	Black with pink markings when young, black with yellow marking when grown up; never green
behavior	Remain scattered on vegetation.	Form groups or bands and march long distances.
No. of moults	5-6	5
Antenna	27-30 jointed.	26-jointed
Eye stripes	6-7	6

❖ **Phase theory:** given by **Uvarov** in **1921**

❖ **Distribution** :-

Widely distribution across the word arid and semi-arid regions, with the desert locust found in North Africa, the middle East southwest Asia and the migratory locust having a vast range across Africa, Asia, Europe and Australia. Other species include the red locust in sub-sahran Africa, the brown locust in Southern Africa and the south American locust in South America.

❖ **Life cycle of locust**

The life cycle consists of three main stages

- **Eggs:** A single female may lay up to 10-11 pods, each pod containing up to 120-140 eggs. A female normally lays 500 eggs in about 5pods. Egg laying female, with the help of her ovipositor, borers a hole into the loose sandy soil, 6-10cm deep. The eggs laid in Feb. and march hatch in 3-4 weeks and those laid in may-September hatch in 12-15 days.
- **Nymphs:** The nymphs, at the time of emerging, break the egg-shell and creep out of the holes. The duration of the nymphal stage lasts 6-8 weeks in spring and 3-4 weeks in summer.
- **Adult:** Full developed locusts possess wings and can fly long distances. Adult live period 2-5 month, depending on environmental conditions. A single swarm may contain billons of individuals capable of traveling 150km in a single day.

❖ **Host plant:-**

Feeds on all vegetation except neem, datura, jamun and sisham

❖ **Damaging stage:-**

Nymphs and adults

❖ **Management and Control:-**

1. Cultural methods:-

- Deep summer ploughing for management of egg masses.
- Digging trenches to trap hopper bands.
- Crushing hoppers mechanically.

2. Physical method:-

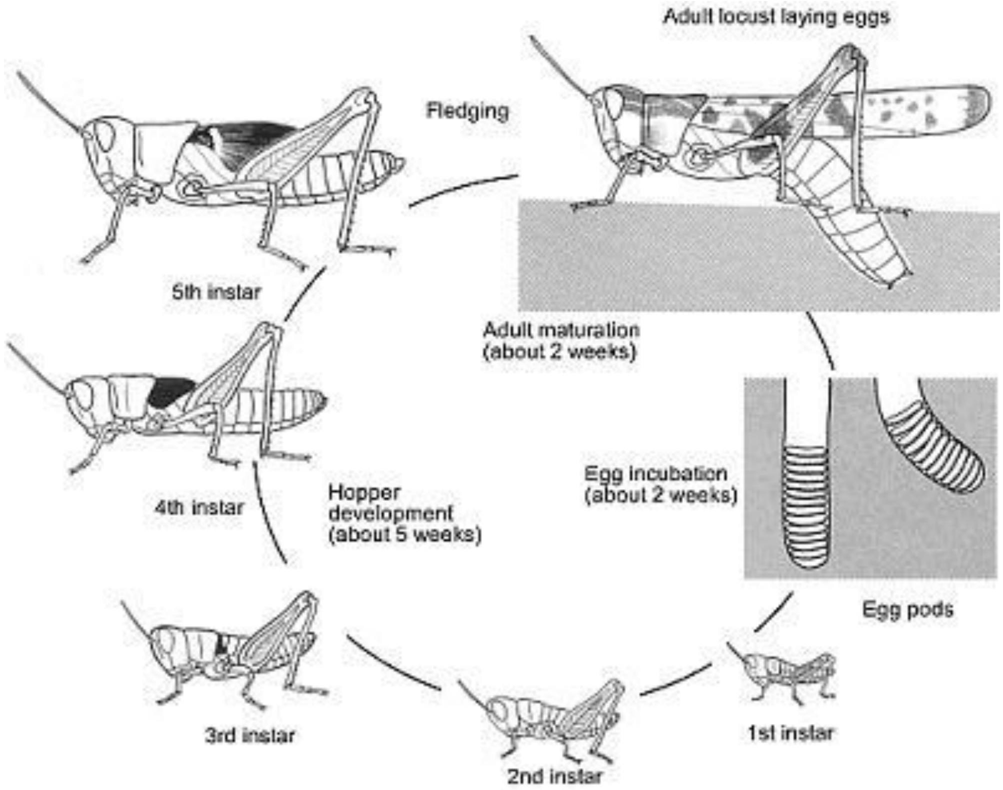
- Sound produce
- Vapour heat treatment(flame thrower)

3. Biological control:-

- Entomopathogenic fungi (Metarhizium anisopliae) are effective against hoppers.
- Natural enemies: Birds, parasitoids, predatory beetles and wasps.

4. Chemical control:-

- Use of ultra-low volume sprayers by aircraft in desert areas.
- Spraying chlorpyriphos 20%EC 240gm/hac.
- Fipronil 5% SC 6.25gm/hac.



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TILLING and Eco-TILLING: Revolutionary Technologies for Plant Functional Genomics and Crop Improvement

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Abstract

In the era of precision agriculture and climate-resilient crops, reverse genetics tools like TILLING (Targeting Induced Local Lesions in Genomes) and Eco-TILLING have emerged as powerful, non-transgenic strategies for dissecting gene functions and harnessing genetic diversity in plants. TILLING enables the discovery of induced mutations in targeted genes, while Eco-TILLING mines natural polymorphisms for breeding applications. This article explores their methodologies, advantages, applications across major crops, and future potential, highlighting their role in sustainable crop improvement without the regulatory hurdles of genetic modification.

Introduction

Plant breeding has long relied on forward genetics, observing phenotypes to uncover underlying genes. But this approach is time-consuming and often inefficient for complex traits like drought tolerance or nutrient efficiency. Reverse genetics flips the script: starting with a gene of interest and disrupting it to reveal its function. Among these tools, TILLING and its derivative, Eco-TILLING, stand out for their versatility across species, high throughput, and avoidance of transgenic elements. Developed in the early 2000s, these technologies have revolutionized functional genomics in plants, from model organisms like Arabidopsis to staple crops like wheat and rice. As global food security faces mounting pressures from climate change and population growth, TILLING and Eco-TILLING offer eco-friendly pathways to enhance yield, quality, and resilience. This article delves into their principles, implementation, real-world impacts, and evolving role in plant science.

The TILLING Technology: Inducing and Detecting Mutations

Historical Development

TILLING was pioneered in 2000 by researchers at the Fred Hutchinson Cancer Research Center, who sought a high-throughput method to screen chemically mutagenized populations of *Arabidopsis thaliana* for mutations in specific genes, such as chromomethylase genes involved in DNA methylation. Building on earlier mutagenesis techniques dating back to the 1930s, TILLING integrated random chemical induction with targeted PCR-based detection, bypassing the limitations of insertional mutagenesis like transposons, which require species-specific vectors. By 2003, it had been streamlined for large-scale use, with the Arabidopsis TILLING Project identifying over 1,890 mutations across 192 genes. Its expansion to crops like maize (2004), wheat (2005), and rice (2007) marked a shift toward practical breeding applications.

Methodology

The TILLING workflow is deceptively simple yet highly efficient. It begins with mutagenesis: seeds or pollen are treated with alkylating agents like ethyl methanesulfonate (EMS), which preferentially induces G/C-to-A/T transitions at rates of 1 mutation per 250–1,000 kb in diploids. Treated M_1 plants are self-pollinated to produce M_2 progeny, from which DNA is extracted and pooled. Target gene regions (1–1.5 kb) are amplified via PCR using fluorescently labeled primers.

The magic happens in heteroduplex formation *viz.,* PCR products are denatured at high temperature and slowly reannealed, allowing mismatched strands (from mutations) to form heteroduplexes alongside perfect homoduplexes. A single-strand-specific endonuclease, such as CEL I from celery, cleaves these heteroduplexes precisely at mismatch sites, producing fragments that sum to the original amplicon length. Cleaved products are resolved on denaturing polyacrylamide gels using systems like the LI-COR DNA Analyzer, revealing cleavage patterns indicative of mutations. Positive pools are deconvoluted by sequencing, with bioinformatics tools like CODDLE and PARSESNP aiding interpretation.

Modern iterations incorporate high-resolution melting (HRM) analysis or next-generation sequencing (NGS) for even greater speed and accuracy, reducing false positives to under 5%. For polyploids like wheat, adjusted pooling accommodates genome complexity, achieving mutation density up to 1/24 kb.

Advantages

TILLING works in any mutagenizable species, regardless of genome size, ploidy, or transformation efficiency and it is crucial for recalcitrant crops like banana or sugarcane. Unlike RNAi or CRISPR, it avoids off-target effects and transgenes, yielding non-GMO mutants that face fewer regulatory barriers. It generates an "allelic series", from silent to nonsense mutations thereby allowing nuanced functional studies, and its high mutation density ensures rapid hit rates. Cost-effective at scale, TILLING has democratized reverse genetics, with public platforms serving thousands of researchers annually.

Eco-TILLING: Harnessing Natural Variation

Concept and Differences from TILLING

While TILLING induces novelty, Eco-TILLING (introduced in 2004) catalogs existing diversity, scanning natural populations or ecotypes for SNPs, insertions/deletions (INDELs), and microsatellites. It skips mutagenesis, instead pooling DNA from diverse accessions with a reference genotype (often 1:1 ratio) to form heteroduplexes from natural mismatches. This makes Eco-TILLING ideal for biodiversity mining in wild relatives or landraces, where induced mutations might not mimic adaptive evolution. The core detection remains identical as that of CEL I cleavage and sequencing analysis, but it excels at rare variants.

Methodology

Eco-TILLING mirrors TILLING post-DNA extraction *viz.*, normalize and pool samples, amplify targets, form heteroduplexes, digest with CEL I, and detect fragments. For high-diversity populations, 2-fold pooling minimizes complexity, while agarose gels or non-denaturing PAGE cut costs for routine use. Sequencing confirms hits, revealing haplotypes for association studies. It is particularly potent in polyploids or heterozygotes, detecting polymorphisms in introns, exons, and repeats with low false negatives (5%).

Advantages

Eco-TILLING accelerates SNP discovery without the 1–2 years needed for mutagenized populations, making it a breeding accelerator for traits like disease resistance. It uncovers hidden allelic richness in germplasm banks, supporting marker-assisted selection, and integrates seamlessly with phylogenetics or GWAS. By targeting positives for sequencing, it slashes costs compared to whole-genome resequencing, democratizing access to natural variation in understudied crops.

Applications in Plant Breeding and Research

TILLING and Eco-TILLING have transformed crop improvement, yielding mutants for yield, quality, and stress tolerance.

In wheat, TILLING targeted waxy genes, identifying 246 alleles including 84 missense and 5 splice-site mutations to produce low-amylose varieties for superior noodle and flour quality. Eco-TILLING mined Mla loci in barley for powdery mildew resistance. Rice TILLING populations (e.g., IR64) uncovered salt-tolerant mutants in OsSOS1 and OsAKT1, while Eco-TILLING flagged OSCP17 variants for drought resilience.

In tomato, TILLING targeted to mutate PSY1 for carotenoid enhancement and IAA9 for improved fruit set, extending shelf life via SlACO1 knockouts. In soybean, Eco-TILLING scanned Gy1–Gy5 for seed protein optimization, and TILLING induced low-phytate lines for better nutrition. Legumes like pea and cowpea benefited from Fusarium wilt resistance alleles via TILLING, with gamma-ray variants boosting yield by 20–30%. These applications extend to biofortification (e.g., provitamin A wheat) and heavy metal tolerance (e.g., Cd-accumulating Brassica mutants), underscoring their versatility.

Future Prospects and Challenges

"TILLING by Sequencing" and exome capture, which integrate with CRISPR for hybrid techniques like precisely editing TILLING-derived alleles, offer near-complete mutant catalogs as NGS costs fall. There are still issues such as backcrossing is necessary for background mutations, optimal methods are needed for polyploid complexity, and sophisticated phenotyping is required for phenotype-genotype correlations. Nonetheless, these instruments will support the domestication of orphan crops and climate-adaptive cultivars in an NGT-friendly regulatory environment, supporting the UN Sustainable Development Goals.

Conclusion

TILLING and Eco-TILLING bridge genomics and breeding, offering a non-transgenic toolkit for a sustainable future. From Arabidopsis labs to global fields, they have unlocked gene functions and allelic treasures, paving the way for resilient crops. As plant science evolves, their legacy endures not as relics, but as enduring enablers of innovation.

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Organic Amendments: The Hidden Power Reviving Soil Health

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1. Introduction: Rediscovering the Energy Beneath Our Feet

Soil is more than just a medium for plant growth—it is a living ecosystem brimming with microorganisms, organic matter, and minerals that sustain life on Earth. However, decades of intensive agriculture and chemical dependency have silently eroded the vitality of our soils. The decline in soil organic carbon, microbial activity, and structural stability has made farming systems increasingly unsustainable.

Organic amendments—such as farmyard manure (FYM), compost, green manure, crop residues, and biochar—offer a natural path to rejuvenate degraded soils. These materials act as energy sources for soil microbes, improve nutrient cycling, and enhance the soil's physical, chemical, and biological properties. This article explores how organic amendments serve as the *hidden power* restoring the energy, fertility, and resilience of our agricultural soils.

2. The Science Behind Organic Amendments

Organic amendments are derived from plant, animal, or microbial residues. When added to the soil, they decompose through microbial action, releasing carbon dioxide, water, and a host of essential nutrients such as nitrogen, phosphorus, and potassium.

Microbial decomposition transforms complex organic molecules into humus—a stable organic fraction that improves soil structure, cation exchange capacity, and nutrient-holding capacity. In essence, organic amendments act as *slow-release energy packs* that feed both the soil microbes and the plants over time.

Modern research has shown that regular organic matter addition increases soil enzyme activities (urease, dehydrogenase, phosphatase), boosts microbial biomass carbon, and creates a favorable environment for root development.

3. Types of Organic Amendments and Their Benefits

Type	Source	Key Benefits
Farmyard Manure (FYM)	Animal dung + bedding material	Improves soil structure, water retention, and nutrient supply
Compost	Decomposed plant/animal waste	Enhances microbial activity and organic carbon content
Green Manure	Leguminous crops like sunn hemp, dhaincha	Adds nitrogen, improves aggregation, suppresses weeds
Crop Residues	Stubble, husks, leaves	Maintains organic carbon and prevents soil erosion
Biochar	Pyrolyzed biomass	Increases nutrient retention and carbon sequestration

Each amendment type contributes uniquely to restoring soil vitality. Combining organic sources with mineral fertilizers has been shown to improve nutrient-use efficiency and sustain yield levels without environmental degradation.

4. Organic Amendments and Soil Microbial Dynamics

Microbes are the *engine* driving soil fertility. Organic amendments act as microbial fuel, increasing both diversity and activity. Bacteria, fungi, and actinomycetes thrive on organic substrates, converting nutrients into plant-available forms.

Rhizosphere microorganisms, stimulated by organic inputs, produce growth-promoting substances like indole acetic acid (IAA), gibberellins, and cytokinins. Moreover, organic inputs support beneficial microbes such as **Azotobacter**, **Rhizobium**, and **Phosphate-Solubilizing Bacteria (PSB)**, which further enhance nutrient availability.

This biological synergy transforms soil into a self-sustaining system—one that recycles nutrients efficiently and minimizes external inputs.

5. Soil Physical and Chemical Improvement through Organic Matter

Organic amendments significantly improve the **physical structure** of soil by increasing porosity, water infiltration, and aggregate stability. This helps in reducing compaction and erosion.

Chemically, they enhance cation exchange capacity (CEC), buffer soil pH, and supply macro- and micronutrients in balanced proportions. They also chelate toxic elements like aluminum and iron in acidic soils, making nutrients more available to plants.

In sandy soils, organic matter acts like a sponge, retaining moisture; in clayey soils, it helps reduce bulk density and promotes aeration. Thus, organic amendments bridge the gap between poor and fertile soils.

6. Organic Carbon: The Hidden Energy Currency

Soil organic carbon (SOC) is often called the *currency of soil health*. Every addition of compost, manure, or residue feeds this carbon pool. Higher SOC means better microbial activity, improved nutrient cycling, and greater resilience to drought and heat stress.

A 1% increase in organic carbon can enhance water-holding capacity by up to 20,000 liters per hectare. Therefore, organic amendments are not just fertilizers—they are *carbon energizers* that empower soil to function as a living, breathing system.

7. Integrating Organic Amendments with Modern Agriculture

For long-term sustainability, integrating organic amendments with **integrated nutrient management (INM)** and **precision agriculture** practices is vital. Combining organics with chemical fertilizers ensures balanced nutrition, reduces nutrient losses, and maintains soil structure.

Recent innovations include:

- **Biochar-based composts**
- **Enriched vermicompost with bioinoculants**
- **Liquid manures (panchagavya, jeevamrutham)**
- **Nano-biochar composites**

These innovations align with India's *Natural Farming* and *Bharat Krishi Revolution 2047* goals, linking tradition with technology.

8. Challenges and Future Perspectives

Despite the benefits, challenges remain—limited availability of organic materials, inconsistent quality, labor-intensive application, and farmers' preference for quick-acting fertilizers.

Future research must focus on:

- Standardizing compost quality parameters
- Developing low-cost biochar units
- Promoting on-farm waste recycling
- Integrating organic inputs into precision nutrient management models

Policy incentives, awareness programs, and training can help bridge the gap between science and practice.

9. Conclusion: Breathing Life Back into Soils

Organic amendments are more than fertilizers—they are life restorers. They nurture soil microorganisms, enhance fertility, improve resilience, and support sustainable agriculture. In the era of climate uncertainty and declining soil productivity, turning back to organic matter is not a step backward but a leap forward.

By unlocking the *hidden power* of organic amendments, we can ensure fertile soils, healthy crops, and a sustainable future for generations to come.

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PM-Kisan Samman Nidhi: Financial Empowerment for Farmers

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Abstract

The Pradhan Mantri Kisan Samman Nidhi (PM-KISAN) Yojana is a Central Sector Scheme launched by the Government of India in 2019 to provide direct income support to all small and marginal farmers. Under this scheme, eligible farmers receive a fixed amount of ₹6,000 per year in three equal installments directly into their bank accounts. The primary objective is to ensure a stable income to support farmers in meeting agricultural and household needs, thereby improving their financial condition and promoting inclusive growth in the agriculture sector.

Keywords: Central sector, Government of India, inclusive growth, agriculture sector.

Introduction

Indian agriculture plays a vital role in the country's economy, employing over 50% of the workforce and contributing significantly to the GDP. However, despite its importance, the sector faces numerous challenges such as unpredictable weather patterns, low productivity, rising input costs, and inadequate access to credit and technology. Small and marginal farmers, who constitute the majority of the agricultural community, often struggle with low and irregular income, pushing them into cycles of debt. In this context, the **PM-Kisan Samman Nidhi Yojana** was introduced to provide direct financial support to these farmers, ensuring a stable income to meet their agricultural and household needs. By offering ₹6,000 per year in three installments, the scheme aims to alleviate financial distress, enhance productivity, and ultimately improve the overall livelihood of farmers, fostering rural economic growth and stability. India is an agrarian economy where a large segment of the population depends on agriculture for their livelihood. Small and marginal farmers, however, often face financial challenges due to unpredictable weather, rising input costs, and fluctuating market prices. To address these issues, the Government of India launched the PM-KISAN Yojana on 1st February 2019, aiming to supplement the financial needs of farmers and ensure better crop health and proper yields.

The scheme was initially meant for small and marginal farmers with landholding up to 2 hectares but was later expanded to include all farmer families regardless of land size, subject to certain exclusion criteria.

Number of Installments per year

Under the PM-KISAN Yojana, eligible farmers receive a financial benefit of ₹6,000 per year, paid in three equal installments of ₹2,000 each:

- **1st installment**: April to July
- **2nd installment**: August to November
- **3rd installment**: December to March

The amount is transferred directly to the beneficiaries' bank accounts through Direct Benefit Transfer (DBT), ensuring transparency and efficiency.

Advantages of PM-KISAN Yojana

1. **Direct Income Support**: Provides a reliable income source to farmers for agricultural and domestic needs.
2. **Financial Inclusion**: Promotes banking and financial services in rural areas through DBT.
3. **Reduction in Debt Dependency**: Reduces dependence on informal sources like moneylenders.
4. **Timely Support**: Helps in timely purchase of seeds, fertilizers, and other inputs.
5. **Economic Boost**: Enhances rural purchasing power, leading to economic development in agrarian areas.
6. **Transparency**: Digital and Aadhaar-linked payments ensure minimal corruption and middlemen.

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7. **Wider Coverage**: Extended to all farmers, improving inclusivity in welfare benefits.

How PM-KISAN Helps Improve the Livelihood of Farmers

- **Stabilizes Income**: With assured yearly income, farmers can better plan their expenditures and investments.
- **Encourages Crop Investment**: Financial aid helps in purchasing quality inputs, improving crop productivity.
- **Reduces Migration**: Economic stability reduces the need for seasonal migration to urban areas.
- **Empowers Women**: Where land is in the name of female farmers, they directly receive the funds, enhancing their financial empowerment.
- **Promotes Rural Development**: Increased income leads to greater spending in rural markets, boosting local businesses and services.

Conclusion

The **PM-Kisan Samman Nidhi Yojana** has proven to be a crucial step in uplifting the economic status of farmers across India. By providing direct financial support, the scheme addresses the immediate financial needs of small and marginal farmers, thereby reducing their vulnerability to market fluctuations and unforeseen agricultural challenges. The timely disbursement of ₹6,000 annually has empowered farmers to invest in their agricultural practices, improve productivity, and secure better livelihoods for themselves and their families. Moreover, the scheme's emphasis on transparency through Direct Benefit Transfer (DBT) has minimized corruption and ensured that the funds reach the intended beneficiaries efficiently. While there is still work to be done in strengthening the agricultural sector, **PM-Kisan** marks a significant move toward achieving financial stability and promoting inclusive growth for India's farming community, ensuring a brighter future for the backbone of our economy.

18.06.2024: - Live telecast of PM Kisan 17th installment programme at KVK, Garikapadu

05.10.2024: Live telecast of PM Kisan 18th installment at KVK, Garikapadu

PM Kisan 18th installment at KVK, Garikapadu

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National Nutrition: Promoting Health through Balanced Diet

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Every year, National Nutrition Week is celebrated in India from 1st to 7th September. It was observed in India in 1982. This was launched with the aim to decrease malnutrition and poor dietary habits across various parts of the country. Since then the government, NGOs, health organizations, women and child welfare department and schools worked together during this week to spread knowledge about nutrition through workshops, seminars, campaigns and social media.

This programme aims to raise public awareness about the importance of nutrition, healthy eating habits and it plays an important role in educating people about how good nutrition can lead to better health and well being.

Proper nutrition is vital for maintaining healthy body weight, strengthening the immune system, improving mental health and cognitive function, and reducing the risk of chronic diseases. Nutrients provide body energy and enable bodily functions. They are usually classified in two major groups: Macronutrients such as carbohydrate, protein and fat, primarily provide energy. The different micronutrients such as vitamins and minerals help to protect body from diseases.

Healthy diet must include nutrient dense foods like

- **Fruits and Vegetables:** Provide fibre, vitamins, and minerals.
- **Whole Grains:** Offer fibre and energy.
- **Lean Proteins:** Such as lean meats, poultry, fish, and beans.
- **Healthy Fats:** Essential for the body's functions.
- **Water:** Crucial for hydration, nutrient transport, and regulating body temperature.

Benefits of nutrition in diet

Improper food habits imbalance the calorie requirements which include both inadequate and excessive energy intake; the former leading to malnutrition in the form of stunting growth and underweight, and the latter resulting in overweight and obesity. Malnutrition in children is the consequence of a range of factors that are often related to poor food quality, insufficient food intake or combinations of both.

- **Energy and Function:**

Nutrients from food act as fuel for the body and enable the brain, muscles, bones, and other organs to function in a right manner.

- **Disease Prevention:**

A balanced diet helps to protect against diseases such as cardiac disease, diabetes and other chronic diseases. Good nutrition strengthens the immune system, fighting off illness and promoting recovery from injury or infection.

- **Weight Management:**

Eating nutritious meals helps to maintain a healthy body weight by providing the necessary energy and nutrients.

- **Mental and Cognitive Health:**

Adequate nutrients are important for brain health, supporting mood and cognitive function

- **Growth and Development:**

Essential for proper physical and mental growth, particularly in children acts as a building blocks.

The Indian consumer segment is dominated by a large urban mass and the youngest populations in the world. Indians spend a high proportion of their incomes on food and groceries, compared to consumers in other countries. Indians have become increasingly health conscious in recent years. Therefore it is necessary to have nutrition awareness campaigns among the population what to eat, how much to eat and nutrient requirements by the body at different age groups.

Balanced Diet for various age groups:

1. **Childhood Nutrition** : It focus on growth and brain development therefore body building foods like milk, egg, fruits, green vegetables, cereals can be given.
2. **Adolescent Nutrition**: There will be hormonal changes, rapid growth and mental development among both gender diets includes iron rich foods namely spinach and other dark coloured green leafy vegetables, protein, calcium rich foods.
3. **Adult Nutrition**: They need to focus on energy balance, maintaining weight and prevention of lifestyle diseases like Obesity. The diet includes whole grains rich in fibre, lean protein, healthy fat and high fiber foods like millets are more suitable according to their region.
4. **Elderly Nutrition**: It focus on preventing bone, as people age, their metabolism slows down, appetite may decrease and absorption of nutrients may become less efficient. Chronic illness and medications can also impact nutritional status. Protein sources include eggs, dairy products, legumes and nuts needed to prevent muscle loss. Calcium and Vitamin D foods essential to prevent osteoporosis and fiber rich foods help in digestion and prevent constipation. Moreover elderly people often have diminished sense of thirst therefore they should be encouraged to be hydrated by intake of liquids.
5. **Pregnancy**: It is a time of increased demand of nutrients for mother's health due to fetal growth and development. Iron rich foods like green leafy vegetables supports increased blood volume and prevents anaemia among pregnant women. Other nutrients such as folic acid, calcium, vitamin D, protein are required for tissue development and growth of the baby and placenta. Therefore they need to eat a variety of whole grains, fruits and vegetables, protein rich foods like dairy products. Avoid consuming raw seafood, eggs, unpasteurized dairy and some vegetables due to the risk of food borne illnesses.
6. **Lactation**: It increases a mother's energy and nutrient needs even more than pregnancy, as the body works to produce breast milk rich in nutrients. Therefore increased calories intake, protein, calcium and micronutrients such as vitamin A, C, D, B-complex, iodine and zinc are required by the lactating mother. A weaning mother can avoid high-mercury fish in the diet, maintain a balanced diet involving all the food groups and need to continue with prenatal vitamins as recommended.

To promote good health, it's important to limit the followings in the diet

- **Saturated and Trans Fats:** Found in processed foods, these can contribute to chronic diseases.
- **Added Sugars:** Found in many processed foods and sugary drinks.
- **Salt:** Excess salt can lead to high blood pressure.
- **Refined flour** : Flours which are deficient in fibre affects digestive system

Conclusion

Nutrition is fundamental at every stage of life span of individual, but at certain period demand for special attention. During National Nutrition Week, it's vital to recognize vulnerable groups such as children, adolescents, elderly, pregnant, and lactating mothers, each have distinct nutritional needs that must be met to ensure optimal health and quality of life. Nutritional qualities among the different groups are closely linked to the overall standard of living and whether a population can meet its basic needs, such as access to food, housing and health care. Growth assessment thus not only serves as a means for evaluating the health and nutritional status of children but also provides an indirect measurement of the quality of life. Dieticians, Health professionals, caregivers and family members should work together to promote balanced diets tailored to each life stage. So that, healthier communities fostered and improve long-term well-being.

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Nanoparticles in the Soil-plant System: Tiny Helpers or Hidden Dangers?

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Abstract

The rising global population and growing environmental pressures are driving agriculture to adopt advanced technologies such as nanotechnology to boost productivity and sustainability. Nanoparticles (NPs) have shown potential in improving nutrient delivery, providing precise pest control, and enhancing soil and crop monitoring. Their nanoscale dimensions and high reactivity enable effective interaction with plants, thereby improving growth, yield, and stress resistance. Nevertheless, concerns remain regarding their persistence, toxicity, and possible adverse impacts on soil microorganisms, crop health, and ecosystems. Current studies are largely confined to laboratory conditions, underscoring the urgent requirement for field evaluations, environmentally safe NP formulations, and clear regulatory guidelines. A comprehensive understanding of NP behaviour within the soil-plant system is crucial to maximise their benefits while minimising risks.

Keywords: *Nanotechnology, Agriculture, Nanoparticles, Soil–plant system, and Sustainability*

Introduction

Nanoparticles are materials smaller than 100 nm, possessing unique chemical, physical, and biological traits distinct from their bulk forms. These characteristics, particularly their high surface area and reactivity, make them suitable for agricultural applications such as nano-fertilizers, nano-pesticides, and nano-sensors. Conventional farming methods, which depend heavily on chemical inputs, often contribute to soil degradation, groundwater pollution, and pest resistance. Nanotechnology provides a more targeted approach, increasing nutrient efficiency and reducing losses, thereby limiting environmental damage. However, the long-term impacts of nanoparticles on soils, plants, and ecosystems remain insufficiently explored, especially under field conditions.

Sources of Nanoparticles in Agriculture

Engineered Nanoparticles (ENPs)

These are synthetically manufactured for agricultural use in fertilizers, pesticides, and sensors. They are designed with controlled particle size, surface coatings, and chemical features, which influence their mobility, bioavailability, and impact on soil systems. While ENPs can enhance yields, issues such as accumulation and toxicity demand close attention.

Natural Nanoparticles

Generated naturally through processes such as rock weathering, volcanic eruptions, and organic matter decomposition, these particles (e.g., metal oxides, silicates, and carbon-based NPs) play a role in soil structure and nutrient cycling. Generally, they are less reactive than engineered counterparts.

Unintentional Sources

Human activities, including industrial emissions, vehicular wear, agricultural residues, and urban runoff, introduce nanoparticles into soil unintentionally. Additionally, environmental breakdown processes like UV exposure and mechanical abrasion can form nanoparticles directly in soils. The source of nanoparticles significantly influences their reactivity, transport, and potential risks in agroecosystems.

Behaviour of Nanoparticles in Soil

The fate of NPs in soil is governed by factors such as pH, texture, organic matter, ionic strength, and microbial activity. Nanoparticles may dissolve, aggregate, or transform chemically, altering their availability to plants. Soil microorganisms can modify NP stability, thereby influencing nutrient cycling and plant uptake. Depending on their persistence, which may last from days to years, NPs can also impact soil structure, water retention, and aeration.

Uptake and Translocation in Plants

Entry Pathways

- **Root uptake:** Nanoparticles penetrate either through cell walls (apoplastic) or across cell membranes (symplastic).
- **Foliar uptake:** Through stomatal openings or direct cuticular penetration, sometimes enhanced by surfactants.

Factors Affecting Uptake

- Smaller particles pass more easily through barriers.
- Positively charged NPs strongly interact with negatively charged cell walls.
- Surface modifications prevent aggregation and improve uptake efficiency.

Translocation

Once absorbed, nanoparticles can move via the vascular system to aerial parts, including shoots, leaves, flowers, and seeds. Their transport is influenced by particle type, plant species, and environmental settings.

Effects on Plant Growth

Positive Impacts

At low doses, nanoparticles such as SiO_2, ZnO, and TiO_2 promote germination, enhance root and shoot growth, increase photosynthetic efficiency, and improve nutrient uptake. For example, ZnO NPs supply zinc gradually, strengthening crop growth and stress adaptation.

Negative Impacts:

High concentrations, particularly of Ag and Cu nanoparticles, may hinder germination, restrict root elongation, induce oxidative stress, and disrupt nutrient balance. Their toxicity arises mainly from their small size and elevated reactivity. Appropriate formulation and dosage are therefore essential.

Impact on Soil Microorganisms

Soil microbial communities regulate nutrient cycling and soil fertility

Positive influence: Low NP doses may stimulate microbial activity and organic matter decomposition.

Negative influence: Antimicrobial nanoparticles (e.g., Ag, Cu) can reduce microbial biomass, suppress enzymatic functions, and lower biodiversity. The extent of impact depends on NP characteristics, exposure level, and soil conditions.

Environmental Concerns

Nanoparticles can persist in soils, altering their chemical and physical properties and potentially entering the food chain via plant uptake. This raises concerns for human and animal health. Leaching may also transport NPs into groundwater, affecting aquatic habitats. The lack of comprehensive regulations and risk assessment frameworks further amplifies uncertainties.

Applications in Agriculture

- Nano-fertilizers: Enable controlled nutrient release, reducing leaching losses.
- Nano-pesticides: Offer targeted pest control with reduced chemical residues.
- Soil remediation: Aid in immobilizing or removing pollutants.
- Nano-sensors: Provide real-time monitoring for precision farming.

Challenges and Risks

- Incomplete understanding of long-term environmental behaviour.
- Lack of standardized regulations and safety assessments.
- Possible human health risks from residues in edible plant parts.
- High manufacturing costs and narrow safety thresholds.
- Developing biodegradable, eco-friendly nanoparticles and implementing stringent risk management strategies are key to safe adoption.

Conclusion

Nanotechnology holds significant promise for sustainable farming by improving nutrient efficiency, enhancing yields, and reducing environmental losses. However, uncertainties regarding toxicity, persistence, and ecological consequences demand further field trials, eco-safe formulations, and robust governance. Moving toward biodegradable nanomaterials and precision nano-agriculture will help balance innovation with ecological and human safety, ensuring responsible integration of nanoparticles into modern farming systems.

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USE OF PLANT AND FRUIT-BASED INGREDIENTS AS AROMATASE INHIBITORS FOR ALL MALE PRODUCTION IN AQUACULTURE

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INTRODUCTION

Aromatase, encoded by the *CYP19A1* gene, is an enzyme responsible for converting androgens into estrogens—a process vital to ovarian formation and sexual differentiation in teleost fish. In aquaculture, the regulation of aromatase activity is often explored as a strategy to influence sex differentiation, particularly to promote male-biased populations in species such as Nile tilapia (*Oreochromis niloticus*), where males typically exhibit faster growth and better feed conversion rates than females.

Synthetic aromatase inhibitors (AIs), including fadrozole and letrozole, have been widely tested for inducing sex reversal. However, concerns about the environmental impact, regulatory acceptance, residue accumulation, and consumer perception of these chemicals have led researchers to consider safer alternatives.

Natural compounds derived from plants and fruits—rich in bioactive molecules such as flavonoids, terpenoids, polyphenols, and alkaloids—have emerged as promising candidates. These phytochemicals can either interfere with aromatase enzyme activity directly or influence its gene expression, ultimately reducing estrogen synthesis. Several studies have reported that botanical extracts, including those from pomegranate, green tea, grape, and turmeric, can promote masculinization in fish while maintaining normal growth and survival. In addition, many of these natural agents possess antioxidant, antibacterial, and immune-enhancing properties, which may contribute to overall fish health and resilience.

This paper reviews the current understanding of plant- and fruit-based aromatase inhibitors in aquaculture, highlighting their bioactive constituents, modes of action, and application potential. It also discusses existing challenges and knowledge gaps to better inform future research on sustainable, eco-friendly approaches to fish reproductive management.

USE OF AROMATASE INHIBITORS IN AQUACULTURE

Aromatase inhibitors (AIs) are chemical agents that block the enzymatic conversion of androgens to estrogens, a key step in sexual differentiation among teleosts. In aquaculture, these inhibitors are studied primarily for their capacity to induce male development by modulating endocrine pathways. When aromatase activity is suppressed, the resulting reduction in estrogen levels causes a relative increase in androgens such as testosterone, promoting male gonadal and phenotypic traits.

The intentional manipulation of sex ratios through AI treatment is particularly advantageous for species in which males exhibit superior growth rates or higher market demand. For example, in Nile tilapia (*Oreochromis niloticus*), the production of all-male populations enhances farming productivity and economic return.

Beyond commercial aquaculture, aromatase inhibition has also been investigated as a potential tool for population management and conservation, where controlling sex ratios may assist in maintaining genetic balance or supporting breeding programs for threatened species. However, excessive or inappropriate use of such inhibitors can disrupt normal endocrine function, leading to physiological and reproductive alterations.

The degree of masculinization achieved through AI application varies widely across species, developmental stages, and treatment protocols. Elevated androgen levels typically manifest as enhanced muscle development, modifications in fin morphology, or changes in coloration—traits that are characteristic of male phenotypes. Understanding these responses is crucial for optimizing dosage and minimizing adverse effects when employing aromatase inhibitors in aquaculture.

USE OF PLANT- AND FRUIT-BASED INGREDIENTS AS AROMATASE INHIBITORS

Numerous plant extracts and plant-derived substances from different species have been shown to have anti-aromatase activity; these could be alternate therapeutic approaches that get around the drawbacks of AIs that are recommended in clinical settings.

1. White Button Mushrooms (*Agaricus bisporus*):

Phytochemicals with anti-aromatase and anti-proliferative properties have been found in white button mushrooms (*Agaricus bisporus*) in vitro. The human placental aromatase was most effectively inhibited by the extract from A. bisporus. Conjugated linoleic acid (CLA) and its derivatives are the main phytochemicals that inhibit aromatase. CLA also alters estrogen receptor activity, reducing growth in MCF-7 cells. In CHO cells, linoleic acid and CLA both inhibit aromatase activity (in-cell test). Stuffing mushrooms demonstrated the best inhibitory impact against aromatase activity among the ten mushroom varieties studied (woodear, crimini, oyster, Italian brown, enoki, baby button, stuffing, shiitake, chanterelle, and portobello).

2. Green Tea (*Camellia sinensis*):

Among the several catechins (flavan-3-ols) that are abundant are the four main catechins: (-)-epigallocatechin-3-gallate (EGCG), which makes up about 59% of all catechins; (-)-epigallocatechin (EGC), which makes up about 19%; (-)-epicatechin-3-gallate (ECG), which makes up about 13.6%; and (-)-epicatechin (EC), which makes up about 6.4%. Catechins have the ability to inhibit aromatase, particularly EGCG and ECG.

3. Black Tea:

In Western nations, the majority drank tea. Aromatase is substantially inhibited by polyphenols (theaflavins, thearubigins, and other oligomers) both in vitro and in vivo. Oligomeric flavanols, including theaflavin (TF-1), theaflavin-3-gallate (TF-2a), theaflavin-3′-gallate (TF-2b), and theaflavin-3,3′-digallate (TF-3), are produced when green tea polyphenols ferment. Green tea polyphenols are not as effective at inhibiting aromatase as black tea polyphenols. Black tea prevents aromatase from converting DHEA to estrogen.

4. Turmeric (Curcuma longa):

Growing widely throughout Asia and Africa, curcuma is the rhizome of the perennial plant *Curcuma longa L*. Curcumin, demethoxycurcumin, and bisdemethoxycurcumin are curcuminoids that are abundant in rhizomes. One important cytochrome P450 enzyme that converts testosterone to estradiol, CYP19A1, is inhibited by curcuminoids. The components of turmeric therefore function as potent aromatase inhibitors.

5. White cabbage(*Brassica oleracea*):

Glucosinolates (GLS) are abundant and have chemopreventive qualities. In MCF10A cells, the fermented product (sauerkraut) demonstrated a significant suppression of CYP19 expression at both the mRNA and protein levels. The most effective inhibitor was sauerkraut juice made from organically farmed cabbage.

6. Flaxseed (*Linum usitatissimum*): Packed in lignans, which are phytoestrogens that structurally resemble estrogen and tamoxifen. Flaxseed contains almost 100 times the amount of lignans found in most foods. Enterolactone, a weaker estrogen than estradiol, is the main lignan in circulation. Eating flaxseed alters the metabolism of steroid hormones and has an impact on growth factor and endocrine pathways and also inhibits 17β-hydroxysteroid dehydrogenase and aromatase.

7. Tabebuia avellanedae (TA):

Indigenous people have long utilized the bark of this Amazonian tree to cure a wide range of illnesses. Strong anti-aromatase activity is demonstrated by naphthofurandione. The potency of TA extract was 148 times higher than that of exemestane and 35.6 times higher than that of letrozole.

8. Humulus lupulus (Hops):

Traditionally, menopausal symptoms were treated with this herb. Aromatase inhibition was shown in vitro (IC_{50} = 4.9 µg/ml). Three out of five breast tissues from high-risk postmenopausal women had decreased aromatase mRNA expression.

9. Glycyrrhiza species (Liquorice):

Comprises the species *G. glabra*, *G. uralensis,* and *G. inflata*. In a dose-dependent fashion, aromatase activity was reduced in all species. The most effective was *G. inflata*, which also decreased the expression of aromatase mRNA and was more efficient in vitro than Humulus lupulus.

10. Coreopsis tinctoria (Snow Chrysanthemum):

Traditional medicine in North America, Europe, and Asia uses Coreopsis tinctoria, sometimes known as snow chrysanthemum. Rich in medicinally valuable flavonoids. Aromatase inhibition was demonstrated by methanol extract (IC50 = 24.9 µg/ml). Using Lineweaver-Burk analysis, compounds like naringenin were found to be competitive inhibitors.

11. 8-Prenylnaringenin (8-PN):

The main polyphenol in hops inhibits aromatase expression, which in turn inhibits aromatase activity both directly and indirectly. Liquiritigenin and 8-prenylapigenin, two other phenolics from licorice (Glycyrrhiza spp.), also exhibited inhibitory action.

12. Naringenin, Naringin, and Quercetin:

Quercetin, naringenin, and naringenin are flavonoids that are often found in citrus fruits. Strong in vitro aromatase inhibitors; naringenin was 10× more effective than quercetin, although both had IC50 values that were comparable to ketoconazole. According to in silico research, quercetin and naringenin bind to the catalytic domain of aromatase, and their different potencies are explained by different hydrogen/hydrophobic interactions. In comparison to controls, tumor aromatase levels decreased by 72% for quercetin, 62% for naringenin, and 59% for naringin.

13. Phytocannabinoids (*Cannabis sativa*):

The active ingredients are Δ9-tetrahydrocannabinol (THC) and cannabidiol (CBD). Both cause apoptosis, delay the cell cycle, and stop cell division. Inhibit MCF7aro cells' aromatase activity. Compared to exemestane, CBD suppressed aromatase activity 65% more effectively than THC (14%). Only CBD lowered aromatase mRNA expression, but both decreased aromatase protein.

14. Chrysoeriol:

Found in pepper, citrus, and rooibos tea. decreases the mRNA and protein of TNFα-induced aromatase in MCF7 cells. works by suppressing the transcription factor EGR-1, which controls the production of CYP19A1 (aromatase). Most likely, CYP19A1 is downregulated as a result of preventing ERK1/2 activation.

15. Citrus Fruits (Citrus spp.):

Citrus peel flavonoids have anti-aromatase and anti-estrogenic properties. The following kinds were examined: *C. deliciosa* (Mediterranean mandarin), *C. aurantium* (bitter orange), *C. tangerina* (clementine), *C. reticulata* (Ponkan tangerine), *C. aurantifolia* (Egyptian lime), *C. sinensis* (navel, Valencia, and Baladi orange), and *C. paradisi* (grapefruit variations). Possible preventative and treatment measures for illnesses reliant on estrogen.

16. *Prunus persica* (Peach):

Prunus persica, or peach, is a member of the Rosaceae family and has long been utilized in Asian medicine to treat conditions affecting women, such as PMS. Extracts work in two ways: they suppress aromatase and strengthen the antioxidant system. Aromatase suppression was also seen in other Prunus species, such as *P. africana* bark and *P. avium* heartwood/resin. Flavones from ginkgo biloba also show anticancer and aromatase inhibition.

17. Pomegranate (Punica granatum):

In addition to Punica protopunica, which is exclusive to the Punicae family. Oil, pericarp, and fermented juice polyphenols reduced aromatase activity by 60–80%. Fermented juice and pericarp polyphenol fractions outperformed aminoglutethimide (positive control AI).

18. Red Wine:

Contains aromatase-inhibiting polyphenols, primarily from grape pits and skins. Red wine, not white wine, has advantages. reduces the production of estrogen in breast tissue by inhibiting localized aromatase activity in vivo. Red wine extracts and alcoholic red wine both suppress aromatase.

9. Grape Seed Extract (GSE):

Procyanidin B dimers are abundant. It inhibits the expression, promoter activity, and enzymatic activity of aromatase. Suppresses estrogen production in breast cancer tissue via:

1. Direct inhibition of aromatase activity.
2. Downregulation of transcription factors **CREB-1** and **GR**, reducing aromatase expression.

10. Java Plum (Eugenia jambolana, Jamun):

Also known as the Jamun fruit, the Java plum is the fruit of the *Eugenia jambolana Lam*,a tree, which grows in Florida, Hawaii, and other tropical regions of the world. Anthocyanidin-rich fruits include peonidin, cyanidin, delphinidin, malvidin, and petunidin. Ethanolic extract (EJAE) inhibited proliferation of breast cancer cell lines. EJAE's inhibition of MCF7-aro cells (aromatase + ERα positive) points toward a direct or indirect effect on aromatase, the enzyme central to estrogen synthesis from androgens. Inhibition in MDA-MB-231 (ERα negative) cells suggests additional pathways beyond just estrogen receptor (ER) modulation, potentially involving aromatic biosynthesis or other signaling cascades.

IMPORTANCE OF ALL-MALE PRODUCTION

Many species in the ornamental fish trade are obviously sexually dimorphic, with aquarium hobbyists generally favoring males because of their more prominent fins and brighter colors. Along with egg-laying species like the red Australian rainbow (*Glossolepis incisus*), dwarf gourami (*Colisa lalia*), rosy barb (*Barbus conchonius*), and Betta fish (*Betta splendens*), these species include livebearers like the sailfin molly (*P. velifera*), guppy (*Poecilia reticulata*), sunset platy (*Xiphophorus variatus*), and balloon molly (*P. latipinna*). Because of their popularity, established male varieties are frequently far more expensive than females, sometimes fetching up to four times the price. The significant price difference between male and female children makes the undertaking profitable, even though raising an all-male population may result in greater overall costs (Fernando and Phang 1994). Therefore, using sex reversal techniques to commercially raise all-male populations of these ornamental fish could significantly increase the aquaculture industry's economic benefits. Tilapia farming is set to become more important in the field of food fish production as aquaculture accounts for a greater share of the world's seafood supply. Hormone-induced sex reversal is now the most popular commercial method for creating male tilapia fingerlings due to its ease of use and effectiveness, which has greatly accelerated the tilapia industry's growth.

CONCLUSION

Inducing masculinization has long been accomplished with synthetic aromatase inhibitors like letrozole and fadrozole. However, interest in plant-based alternatives has increased due to worries about their market appeal, ecological dangers, regulatory restrictions, and residual effects. As natural artificial intelligence (AI), fruits and medicinal plants, which are known to be abundant in phytochemicals including flavonoids, tannins, saponins, and terpenoids, have demonstrated significant promise as a safer and possibly multipurpose tool for managing fish reproduction.

The use of plant-based AIs in commercial aquaculture is still in its infancy despite these benefits. To guarantee constant efficacy and safety, a number of significant issues need to be resolved. Inconsistent outcomes might arise from variations in plant chemical composition brought on by species variances, growth environments, and extraction techniques. In conclusion, aquaculture has a lot of potential for the future if fruits and plants are used as natural aromatase inhibitors. Utilizing plant-based AIs could be a useful tactic for managing sex ratios while also enhancing fish health and reducing environmental impact as the business moves toward more ethical and sustainable methods. Botanical aromatase inhibitors have the potential to soon become a commonplace tool in contemporary aquaculture systems, supporting the twin objectives of sustainability and production, provided they have the necessary validation and regulatory backing.

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Sustainable Aquaculture Practices for Rural Development and Livelihood Security

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Introduction

Sustainable aquaculture is the fastest-expanding sector in global food production and is identified as a major rural development, poverty reduction, nutrition security, and environmental protection approach. Aquaculture contributes over 50% of human population consumption of fish globally, and over 75% of the total production comes from developing nations, where rural people rely predominantly on aquaculture and fisheries for income and food security (FAO, 2020 and Olaganathan et al.,2017).

Rural areas tend to have constraints such as low job opportunities, poverty, malnutrition, and resource depletion. Sustainable aquaculture combines scientific techniques with indigenous knowledge to culture fish and other aquatic creatures in sustainable, socially equitable, and economically sound means. Sustainable aquaculture increases rural income diversification, empowers poor people, and improves nutrition and hence becomes the focal point of integrated rural development strategies (Bunting et al., 2023).

Economic Impact and Livelihood Generation

Income and Employment Generation

Sustainable aquaculture contributes significantly to the generation of rural income. Experience has shown that aquaculture can generate 20% to 50% of rural people's incomes depending on the production system and local socio-economic conditions. It is labor-intensive relative to the majority of other agribusiness industries and is directly utilized by employing farmers for fish rearing, hatcheries, feed factories, and processing (Olaganathan et al.,2017). Aquaculture directly employs nearly 16 million people and indirectly supports nearly 36 million through allied businesses, on which more than 100 million rely in India. Women are as important, especially in post-harvest management, marketing, and processing, which are household welfare and gender empowerment determinants (Olaganathan et al.,2017 and Bunting et al., 2023).

Indirect employment opportunities for input supplies like fish feed production, hatchery activities, and equipment manufacturing also exist in aquaculture. The spillover effect resulting from the operation of fish farms creates rural enterprises for value addition and marketing, fostering rural entrepreneurship (FAO,2020).

Poverty Alleviation and Socio-economic Upliftment

Fisheries and aquaculture are a gateway to poverty alleviation, particularly for the historically deprived groups located in far-flung rural areas. Evidence from Bangladesh shows that members of fish farm households have lower absolute and hardcore poverty compared to other farm household members, reflecting the economic vulnerability provided by aquaculture (Khanum et al.,2022).Due to generating sure cash incomes, fish farming provides entry to accumulation of assets and enhanced living standards, education, and well-being. Apart from that, the availability of government scheme and credit facility under schemes like the Indian Pradhan Mantri Matsya Sampada Yojana (PMMSY) promotes small-scale aquaculture and hence improves living standards.

Investment made in fish farms typically helps develop rural infrastructure ponds, water management infrastructure, storage sheds, and roads serving various sectors. The development of these rural riches sustains diversified income streams and strengthens rural economies (Press Information Bureau, 2025).

Food Security and Nutritional Outcomes

Protein Security and Micronutrient Benefits

Fish is an animal food high in protein and essential amino acids, omega-3 fatty acids, vitamins (A, D, B12), and minerals like calcium, phosphorus, and iodine. They are entirety irreplaceable in vulnerable groups of pregnant and lactating women, infants, and children below five years of age, who suffer from multiple micronutrient deficiencies in developing nations (Sridevi et al.,2024).

Small locally abundant fish species, commonly harvested from homestead ponds or integrated systems, are most valuable in terms of offering low-cost feed. These species yield micronutrients of greater amounts than what is found in conventionally consumed local meat or vegetable sources and hence help combat prevalent malnutrition such as stunting, wasting, and anemia.Rural Indian village studies have shown that family intake of greater quantities of fish through aquaculture interventions enhances household nutritional status, lowering rates of undernutrition and improving cognitive development of children. Therefore, aquaculture not only minimizes calorie deficiency but also micronutrient deficiency for long-term health gain (Olaganathan et al.,2017 and Sridevi et al.,2024).

Strengthening Local Food Systems

The incorporation of aquaculture within domestic food systems enhances the diversity of food choices and improves food supply shock resilience. Multiflowering production systems such as rice-fish culture or integrated agriculture-aquaculture systems (IAAS) enhance farm productivity with multiple access to cereals, vegetables, and fish protein at the same time. Multiflowering systems decrease dependency on foreign food aid and imports, improve local markets, and provide year-round food accessibility. Sustainable aquaculture improves the resilience of rural economies through improving food sovereignty and local value chains (Olaganathan et al.,2017 and Hasimuna et al.,2023).

Sustainable Production Systems

Integrated Multi-Trophic Aquaculture (IMTA)

IMTA utilises a co-culture of various trophic level species, such as finfish, shellfish, and seaweed, in the same system to efficiently recycle nutrients, minimise organic waste, and sustain ecological balance. This system replicates natural conditions, enhances water quality, and enhances overall production efficiency. IMTA systems exhibit remarkable water savings (30-50%), minimized feed losses, and improved potential for biodiversity, offering a novel and sustainable avenue compared to monoculture aquaculture (Sarker,2023 and Pathak, 2024).

Recirculating Aquaculture Systems (RAS)

RAS technology is a big step towards environmental sustainability. Recycling over 95% of water and having closed systems, RAS decreases freshwater withdrawal, effluent discharge, and provides ideal growth and fish health conditions. RAS is very capital-intensive in the beginning but is becoming more affordable as technology costs decrease and governments subsidize it, hence suitable as a solution for peri-urban and urban aquaculture (Penot et al.,2024).

Rice-Fish Integration Systems

Aquaculture in rice paddies irrigated with water utilizes available agricultural land to grow several food crops synergistically. These systems enhance farm revenues and food variety with little additional land or labor inputs, meeting grain and protein needs. Rice-fish farming systems also enhance soil fertility, regulate pests, and minimize methane emissions than rice monoculture and promote climate-smart agriculture practices (Mohanty et al., 2004).

Environmental Sustainability

Resource Conservation and Pollution Reduction

Modern sustainable aquaculture practices like biofloc technology and aquaponics reduce water use by up to 90% compared to traditional open pond systems by recycling nutrients in closed or semi-closed loops. These innovative technologies conserve scarce water resources, vital in water-stressed rural areas.The reliance on alternative feeds made from plants, insects, and microbial proteins reduces the environmental burden caused by using wild fish for feed (fishmeal), thereby protecting marine ecosystems and reducing overfishing (Mansour et al.,2025).

Ecosystem Protection and Biodiversity

Mangrove aquaculture integrates shrimp cultivation and replanting of mangroves to create wildlife habitat, stabilize coastlines, and enhance water purification. These systems illustrate that ecological restoration may coexist with sustainable production. Ecological practices, including polyculture and integrated agriculture, minimize disease outbreaks, the application of chemicals, and loss of habitat with intensive monoculture farming (Sathoria & Roy, (2022).

Technology and Innovation

Digital and Precision Aquaculture

The adoption of IoT and AI technologies enables precision fish farming, whereby farmers monitor water quality parameters, optimize feeding schedules, and track fish health in real-time. Studies show these systems can reduce water use by 25-40%, feed waste by 20-30%, and energy consumption by 25-50% while increasing yields.Such digital transformation improves resource efficiency, reduces operational costs, and enhances environmental sustainability in rural aquaculture operations (Boyd et al.,2024).

Alternative Feeds and Sustainable Inputs

Developments in alternative feed sources plant proteins, insect meal, and single-cell proteins help mitigate the environmental and economic constraints posed by conventional fishmeal and fish oil feeds. These feeds improve feed conversion ratios, reduce greenhouse gas emissions, and lower production costs (Mansour, 2025).

Government Support and Policies

Financial Schemes and Subsidies

Government initiatives like India's PMMSY provide critical financial support to fish farmers, with subsidy rates of 40% for general and 60% for SC/ST/Women beneficiaries. The scheme has benefited over 47 lakh fish farmers, facilitating credit access and infrastructure development. Other programs such as the Fisheries and Aquaculture Infrastructure Development Fund (FIDF) invest in cold chains, hatcheries, and mechanization to boost productivity and market access (CIBA, 2020).

Capacity Building and Extension Services

Governments along with NGOs provide training, technical support, and awareness programs to help farmers adopt sustainable aquaculture practices, better disease management, and market linkages. Community Resource Persons (CRPs) and Aquaculture Business Schools have been effective models for skill and knowledge dissemination (NABARD).

Challenges and Solutions

Technical and Environmental Challenges

Common challenges include disease outbreaks, water pollution, lack of adequate regulations, unstable market prices, and climate change impacts. Adopting best management practices, biosecurity measures, certification schemes, and eco-labeling helps address these constraints. Technology transfer and innovation adoption remain uneven, especially in remote and resource-poor rural communities, underscoring the need for enhanced extension services (Chouhan & Choudhary, 2025).

Market Access and Infrastructure Constraints

Many rural fish farmers lack access to modern marketing and cold storage facilities, limiting their ability to capture premium markets. Strengthening rural infrastructure, incubation centers, and farmer cooperatives can improve bargaining power and income stability (Subasinghe, et al.,2009).

Future Prospects and Recommendations

Scaling up Sustainable Practices

Expanding aquaculture into marginal lands, integrating with irrigation systems, and employing climate-resilient technologies can amplify sector contributions to rural development (Halwart et al..,2003).

Policy and Institutional Coordination

Aquaculture must be mainstreamed into broader rural planning and water resource management to achieve holistic sustainability (Boyd et al.,2024).

Continued Research and Innovation

Investment in climate-smart aquaculture, sustainable feeds, and integrated farming systems is crucial for balancing productivity goals with ecological constraints (Mansour, 2025).

Conclusion

Sustainable aquaculture plays a pivotal role in transforming rural livelihoods by generating income, enhancing food security, and protecting environmental resources. Through integrated technologies, supportive policies, and inclusive practices, aquaculture can sustainably meet rising protein demands while empowering rural communities. A coordinated approach encompassing research, capacity building, and infrastructure development is imperative to unlock the full potential of sustainable aquaculture for inclusive rural development and livelihood security in the coming decades.

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Genetically Engineered Crops for Sustainably Enhanced Food Production Systems

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Abstract

Genetic modification of crops has substantially focused on improving traits for desirable outcomes. It has resulted in the development of crops with enhanced yields, quality, and tolerance to biotic and abiotic stresses. With the advent of introducing favorable traits into crops, biotechnology has created a path for the involvement of genetically modified (GM) crops into sustainable food production systems. Although these plants heralded a new era of crop production, their widespread adoption faces diverse challenges due to concerns about the environment, human health, and moral issues. Mitigating these concerns with scientific investigations is vital. Hence, the purpose of the present review is to discuss the deployment of GM crops and their effects on sustainable food production systems. It provides a comprehensive overview of the cultivation of GM crops and the issues preventing their widespread adoption, with appropriate strategies to overcome them. This review also presents recent tools for genome editing, with a special focus on the CRISPR/Cas9 platform. An outline of the role of crops developed through CRSIPR/Cas9 in achieving sustainable development goals (SDGs) by 2030 is discussed in detail. Some perspectives on the approval of GM crops are also laid out for the new age of sustainability. The advancement in molecular tools through plant genome editing addresses many of the GM crop issues and facilitates their development without incorporating transgenic modifications. It will allow for a higher acceptance rate of GM crops in sustainable agriculture with rapid approval for commercialization. The current genetic modification of crops forecasts to increase productivity and prosperity in sustainable agricultural practices. The right use of GM crops has the potential to offer more benefit than harm, with its ability to alleviate food crises around the world.

KEYWORDS: GM crops, genome editing, sustainable agriculture, food production, environmental constraints

Introduction

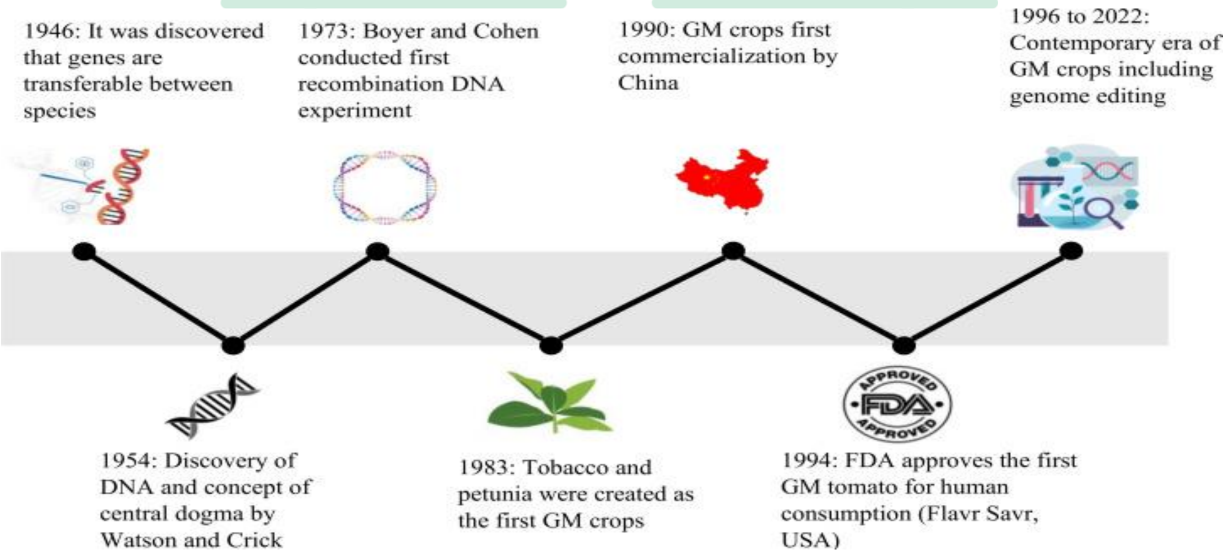
Agriculture faces severe challenges for delivering food and maintaining nutritional security through sustainable practices. relation to the concept of sustainability, sustainable agriculture is defined as a system of growing crops for the short and longterm period without damaging the environment, society, and the economy for the present and future generations. The main goals of sustainable agriculture are to produce high yield of healthy crop products, efficiently use the environmental resources with minimal damages, enhance the quality of life within the society through the just distribution of food, and provide economic benefits for the farmers. These goals have become a prominent issue of discussion in agriculture in the past few years and have been recognized widely in scientific communications, since it is difficult to produce large amounts of food with minimal environmental degradation. However, there has been a remarkable breakthrough in the field of agriculture through plant genetic modification. Plant biotechnology has generated products that helped agriculture sector to achieve enhanced yields in a more sustainable manner. It has witnessed an increase in the production capacity that is as huge as it was during the period of the green revolution in the early 70's. A genetically modified (GM) crop is defined as any plant whose genetic material has been manipulated in a particular way that does not occur under natural conditions, but with the aid of genetic techniques .Agriculture is the first sector that invested heavily in the use of genetic modifications. The massive experiments in agricultural biotechnology have enabled the development of suitable traits in plants for food production. The employment of genetic tools for the introduction of a foreign gene, as well as the silencing and expressing of a specific gene in plants, have brought a dramatic expansion of GM crops. It has led to the propagation of crops that are disease resistant, environmental stress tolerant, and have an improved nutrient composition for consumers.

In the twenty-first century, the genetic modification of crops is considered a potential solution for achieving the goals of sustainable agriculture. However, the use of GM crops has raised complex issues and dilemmas related to their safety and sustainability. There have been several debates which have led some countries to contest the use, cultivation, and commercialization of GM crops specifically, the majority of European and Middle Eastern countries have imposed full or partial limitations on the commercialization of GM crops. Regulatory approval for the commercialization of GM crops is hampered by poor communication and awareness brought about by consumer mistrust. Moreover, the difficult process of completing risk assessments and meeting biosafety regulations has only compounded the existing mistrust of GM crops, based on ethics, history and customs.

Nevertheless, because the GM crops are considered as good candidates for sustainable food production, it is imperative to perform the risk assessment of any developed GM crop, exploring their negative and positive consequences for the current agricultural developments. In this regard, the goal of the present study is to evaluate the use of genetic manipulation and genome editing of crops for overcoming the global food challenges in a sustainable manner. It aims to review current knowledge of GM crops, the concerns and dilemmas associated with them and provides appropriate solutions to overcome them. The study further delivers several perspectives on their incorporation into sustainable food production systems and eliminate the mistrust placed on GM crops for the achievement of Sustainable Development Goals (SDGs).

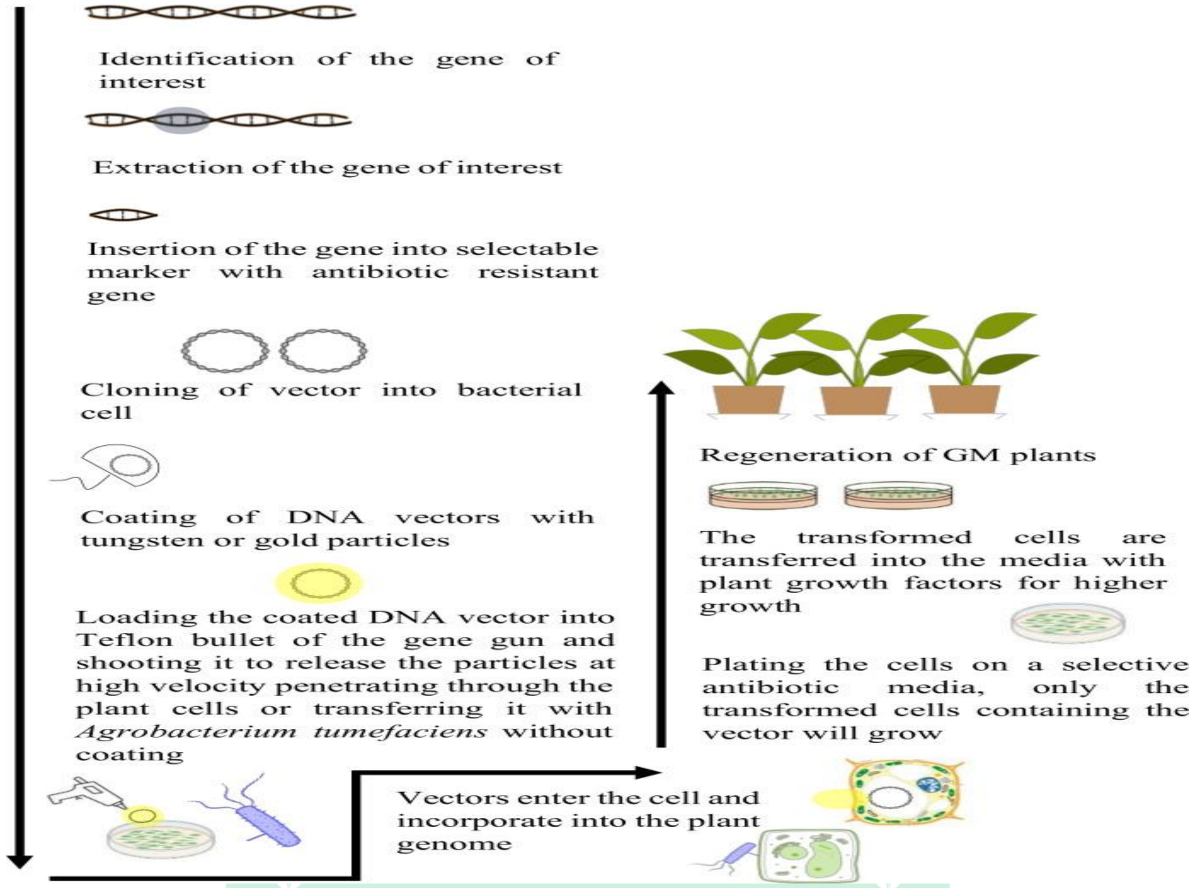
Development Pathway for GM Crops over the years

The genetic modification of plants dates back approximately 10,000 years with the practice of artificial selection and selective breeding. The selection of parents with favorable traits and their utilization in breeding programs has facilitated the introgression of these traits into their offspring's. For instance, artificial selection of maize out of weedy grasses having smaller ears and less kernels, has resulted in the generation of edible maize cultivars. In 1946, the advancement leading to contemporary genetic modification took place, with the scientist's discovery of genetic material being moveable between various species. This was accompanied with the identification of the double helical DNA structure and concept of the central dogma in 1954 by Watson and Crick. Successive advances in the experiments by Boyer and Cohen in 1973 that included the extraction and introduction of DNA between various species resulted in the engineering of the World's first GM organism. In 1983, antibiotic resistant tobacco and petunia, first GM crops, were auspiciously developed by three independent scientists.



2.1 Method of genetic modification of crops

The creation of a GM crop is a complex phenomenon that involves several steps, from the identification of the target gene to the regeneration of transformed plants



2.1.1 Target gene identification

Developing a GM plant requires the determination of the gene of interest for a particular trait such as drought tolerance gene that is already present in a specific plant species. The genes are identified using the available data and knowledge about their sequences, structures, and functionalities. In case of an unknown gene, a much laborious method will be used, such as map-based cloning. The gene of interest is isolated and amplified using the Polymerase Chain Reaction (PCR). It allows the desired gene to be enlarged into several million copies for the gene assembly.

2.1.2 Cloning of the gene of interest and its insertion into a transfer vector

After several copies of genes are attained, it is inserted into a construct downstream a strong promoter and upstream a terminator. This complex is then transferred into bacterial plasmid (manufacturing vectors), allowing for the duplication of gene of interest within the bacterial cell. The DNA construct with the gene of interest is introduced into the plants *via Agrobacterium tumefaciens* or gene gun (particle bombardment).

2.1.3 Modified plant cells selection and plant regeneration

When using antibiotic resistance as a selectable marker gene, only transformed plant cells survive and will be regenerated to entire plant using different regeneration techniques. Several genetic analyses are performed for the determination of insertion and activation of the gene of interest and its interaction with different plant pathways that may cause unintended changes in the final traits within the plants.

The transformed plants are introduced into the field conditions and risk assessments are performed for their environmental and health impacts). Nonetheless, plants with foreign genes have remained in the scrutiny of society for crop production. To overcome these concerns related to transgenic crops, newer biotechnological techniques, such as cisgenesis and intragenesis, are developed as alternatives to transgenesis. In these methods, genetic materials used for trait enhancement are from identical or related plant species with sexually compatible genes.

Besides these techniques, genome editing tools has enabled the plant transformation with ease, accuracy, and specificity. Some of these methods including Zinc Finger Nucleases (ZFNs), Transcription Activator-Like

Effector Nucleases (TALENs), and Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR)/Cas system, were directed towards the concerns related to the unpredictability and inefficiency of traditional transgenesis . These tools are set for developing enhanced plant varieties through accurate modification of endogenous genes and site-specific introduction of target genes.

2.2 Status of GM crops

The global production status of GM crops has increased between the year 1996 to 2019, from 1.7 to 190.4 million ha with approximately 112-fold increase. Subsequently, a large increase occurred in the commercialization of GM crops at an elevated rate in the history of present-day agriculture. Currently, the world's largest GM crops producer is USA with 71.5 Mha (37.5%), with GM cotton, maize, and soybean accounting for 90% of its production. Brazil was the second largest GM crops producer with 52.8 Mha (27.7%) and Argentina was the third largest producer with 24 Mha. Canada and India were fourth and fifth largest producers with 12.5 and 11.9 Mha, respectively.

Percentage of Globally adopted GM crops and their production area (hectares) in various countries. The largest proportions of GM crops grown are soybeans (48%) and the USA covers a substantial area of 71.5 Mha with different GM crops.

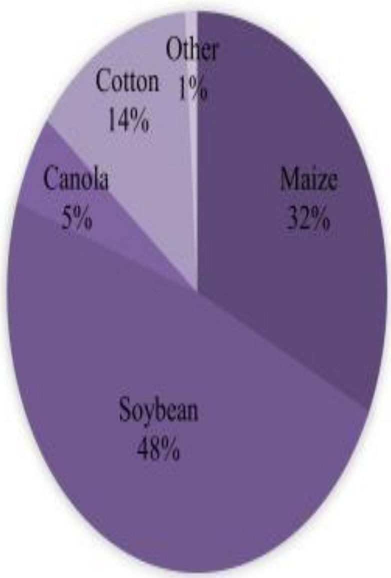


Table 1. The proportion of area covered and common GM crops in various parts of the world.

No.	Continent	Country	Area (Mha)	Common GM crops
1	North America	United States	71.5	Cotton, papaya, alfalfa, sugar beet, rapeseed, soybean, maize, and squash
2	South America	Brazil	52.8	Soybean, cotton, and maize
3	South America	Argentina	24	Cotton, soybean, and maize
4	North America	Canada	12.5	Soybean, sugar beet, rapeseed, and maize
5	Asia	India	11.6	Cotton
6	South America	Paraguay	3.8	Maize, soybean, and cotton
7	Asia	China	2.9	Tomato, sweet pepper cotton, papaya, and poplar

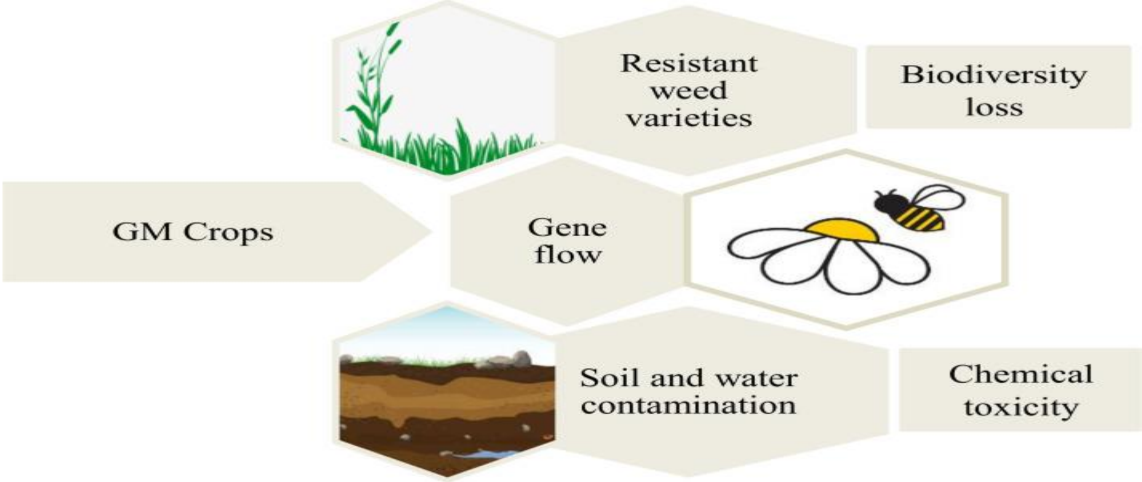
No.	Continent	Country	Area (Mha)	Common GM crops
8	Asia	Pakistan	2.8	Cotton
9	Africa	South Africa	2.7	Cotton, soybean, and maize
10	South America	Bolivia	1.3	Soybean
11	South America	Uruguay	1.3	Maize and soybean
12	Asia	Philippines	0.6	Maize
13	Australia	Australia	0.8	Rapeseed and cotton
14	Asia	Myanmar	0.3	Cotton
15	Africa	Sudan	0.2	Cotton
16	North America	Mexico	0.2	Soybean and cotton
17	Europe	Spain	0.1	Maize
18	South America	Colombia	0.1	Cotton and maize
19	Asia	Vietnam	0.1	Maize
20	North America	Honduras	< 0.1	Maize
21	South America	Chile	< 0.1	Rapeseed, soybean, and maize
22	Africa	Malawi	< 0.1	Cotton, cowpea, and banana
23	Europe	Portugal	< 0.1	Maize
24	Asia	Indonesia	< 0.1	Cotton
25	Asia	Bangladesh	< 0.1	Eggplant
26	Africa	Nigeria	< 0.1	Cowpea
27	Africa	Eswatini	< 0.1	Cotton
28	Africa	Ethiopia	< 0.1	Cotton
29	North America	Costa Rica	< 0.1	Soybean and cotton
		Total	**190.4**	

3. Concerns and Issues related to GM Crops

The inception of GM crops has been controversial mainly due to the ethical concerns and issues of sustainability surrounding the negative impacts of GM crops. These issues range in different forms such as the detrimental effects of GM crops on the environment and human health, the ideology of creating new life forms within the society, and the intellectual property ownership of GM crops that provides economic benefits to specific people. Most of these issues arise due to the arguments that farmers and seed companies attain the benefits of the GM crops rather than the consumer.

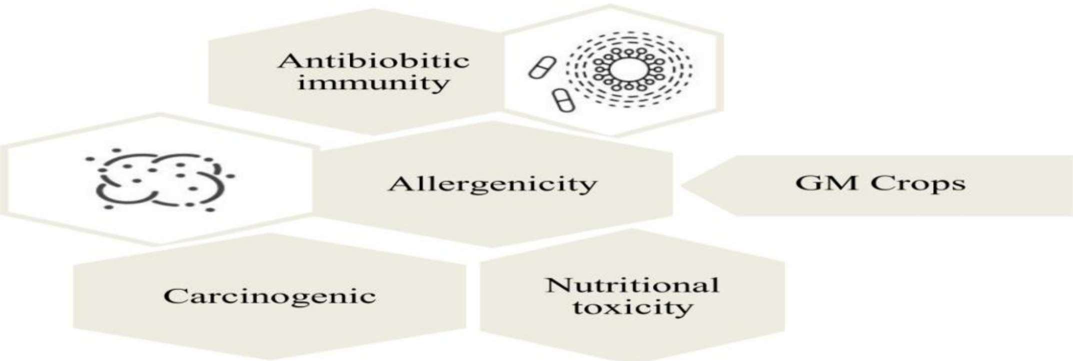
3.1 In relation to the environment

The introduction of GM crops may cause adverse impacts on the environmental conditions, which has been raised ethically by certain sections of the society. It has been argued that the GM crops pose a threat to the decline of crop biodiversity due to of the hybridization of GM crops with related non-GM crops through the transfer of pollen. The GM crops may become invasive over time and affect the population of local wild crop species. The use of specific chemical herbicides for controlling weeds that grow in the fields with GM crops tolerant to that chemical herbicide will lead to the appearance of highly resistant weeds that will be difficult to control. Due to the high use of chemicals to control those weeds, soil and water degradation can also occur . The use of GM crops can have negative impacts on non-target organisms such as predators and honeybees. For instance, the spread of the genetically manipulated herbicide tolerant corn and soybean, with the use of chemical herbicides has damaged the habitat and population of the monarch butterfly in North America. It is considered that such environmental risk raised by the GM crops is difficult to be eliminated.



3.2 In relation to the human health

The biggest ethical concern for the genetic modification of crops is their harmful effects on the human beings. It is assumed that consumption of the GM crops can result in the development of certain diseases that can be immune to antibiotics . This immunity develops through the transfer of antibiotic resistant gene from the GM crops into humans after the consumption. The long-term effects of GM crops are not known, which decreases their consumption rate. It is also found that a number of cultural and religious communities are against these crops and considers them detrimental for humans. It is believed that GM crops can trigger allergic reactions in human beings. In a study conducted for enhancing nutritional quality of soybeans (Glycine max), a methionine-rich 2S albumin from the Brazilian nut was transferred into transgenic soybeans. Since the Brazil nut is a common allergenic food, the allergenicity testing of transgenic soybean indicated allergenic reaction on three subjects through skin-prick testing. This allergenicity was associated to the introduction of 2S albumin gene of Brazil nut into the soybeans. There are also assumptions that GM crops can cause the development of cancerous cells in human beings. It is argued that cancer diseases are caused due to the mutations in the DNA, and the introduction of new genes into human body may cause such mutations. Antibiotic resistance genes from genetically modified plants, used as selectable marker genes can get transferred to bacteria in the gastro-intestinal tract of humans. However, the risk of such occurrence is very low, but it has to be considered when assessing the biosafety of the transgenic plants during field trials or commercialization approvals. The health risk of foods derived from genetically engineered crops are still being debated for rigorous evidence among the scientific community.



Human health related threats of GM crops. The consumption of GM crops is widely associated with toxicity and allergenicity of human beings.

3.3 In relation to the development and intellectual property rights of GM crops

In the ethical debate of GM crops for sustainability, the philosophical reasons are fundamental against the development of these crops. It is viewed that genetic modifications of crops are inappropriate interference in the life of an organism. The gap in this ethical ideology is aggravated in developing countries due to the prominent role of large Biotech companies in deciding how life forms are to be altered to make benefit from them. The concerns of the intellectual property rights, patents of these crops and their ownerships are at the heart of the ethical issues.

The private sector provides the majority of agricultural inputs such as the fertilizers, pesticides and seeds of improved crop varieties that farmers stored and reused season to season. This practice of seed reuse has made it difficult to gain benefits from the investments in artificial breeding. Nonetheless, production of hybrid species and advances in genetic technologies, it became possible to protect the new crop varieties that were developed, especially the larger-volume crops, such as the soybean and maize plants. This is particularly true for the genetic modification tools, which provide producers a stronger intellectual property right for their plants. The patent rights provide monopoly power to the seed companies, which require the farmers to purchase the seeds from the patent owners during each year of plantation. These seeds are known as terminator seeds that develop into infertile crops. The terminator technology was used for developing such seeds that prevented the diversion of genetic modifications to other plants, but limited farmers seed propagation. This made farmers to purchase new seeds during each growing season, giving seed producers larger authority over the utilization of their seeds. It is considered to be ethically wrong to develop plants whose seeds are sterile that farmers cannot use for the second year of plantation. However, terminator seeds that produced infertile crops were temporarily terminated. The intellectual property rights for the GM crops provided protection to the crop varieties and limited farmers in using the seeds of GM crops for another cycle. Moreover, intellectual property rights created a barrier for innovation as it provided a limited access to GM crops for several purposes.

Despite of these concerns of the GM crops, they are considered as one of the tools for achieving the sustainable food production. However, it needs to be evaluated for possible solutions for their negative impacts in securing their benefits.

Potential solutions for growing, commercializing, and incorporating GM crops into sustainable food production systems

The detrimental effects of the GM crops can be reduced or eliminated through appropriate an measure that needs to be taken at different stages of incorporation, marketing and human consumption for ensuring that the GM plants are as harmless as the non-GM crops. This will lead to meeting the goals of sustainability and allow for the incorporation of GM crops into sustainable food production.

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Applications of Sensors in Aquaculture for Disease Prevention and Biosecurity Management

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Abstract

The aquaculture is the fastest growing food sector to satisfy the increasing global seafood demand. However, intensified culture makes the farms vulnerable to diseases. Therefore, it is the need of the hour for early detection, strict policies to avoid outbreaks, limited usage of antimicrobials, and safe production. Sensors can be used together with Internet of Things (IoT) networks and analytics to provide constant monitoring, quick reactions and more intelligent decisions about management. Sensor technologies have been described as an indispensable enforcement of continuous real-time monitoring, disease prevention, and biosecurity in the modern aquaculture systems. The article discusses the wide range of sensors applicable to aquaculture, which are broadly divided into pathogen and biosecurity sensors, behavioral and biomonitoring devices, environmental sensors and more sophisticated smart systems.

Keywords: Aquaculture, disease outbreaks, biosecurity, sensors, Internet of Things

Introduction

The intensification of aquaculture has added pressure on the need to have dependable technologies to overcome disease outbreaks and provide sound biosecurity (Su et al., 2020). Sensors are one among the technologies and act as key tool for continuous monitoring and early warning. Dissolved oxygen, pH, ammonia, and turbidity sensors are water quality sensors, which give important real-time data to alleviate stress conditions. Biosensors, immunosensors, and environmental DNA samplers are becoming complementary to pathogen detection methods. Indirect indicators of health are observed using behavioral sensors such as underwater cameras, hydrophones, and biotelemetry tags. Environmental sensors (complementary devices, like light), weather sensors and gas sensors are used to monitor light, weather, gas emissions, and to support access control on the farm level, RFID, surveillance cameras. Together, these sensor technologies provide greater surveillance, high-speed reaction, and firmer biosecurity systems in aquaculture, which leads to more sustainable and resilient production systems (Rastegari et al., 2023).

Importance of Disease prevention and Biosecurity Management

Successful aquaculture activities lie in disease prevention. Diseases cause mortalities, reducing the productivity and endangering the food supply (Bohara et al., 2024). Proactive, responsive and precision-based farm management, relies on sensors along with advanced internet-of-things (IoT) networks (Ahmed et al., 2024). Epidemics are usually foreshadowed by the changes in water quality (low oxygen, large amounts of ammonia), fish behavior (decreased feeding, lethargy) or pathogen mixtures at low concentrations. These early warning signs can be detected by sensors. A continuous data can be used to note trends and automatic alarms for quicker intervention before a disease outbreak (Shete et al., 2024).

Different of sensors relevant to disease management

1) Pathogen and biosecurity sensors

Pathogen and biosecurity sensors are fast and on-site diagnostic instruments to evaluate microbes (bacteria, virus, parasites), toxins, or genetic materials in aquaculture. The sensors improve disease surveillance and safeguard the health of animals.

a. Electrochemical Biosensors

The principle of this biosensor is the use of an electrode which is coated with DNA probes, antibodies or aptamers that produce electric impulses when bound to the specific DNA, RNA, or protein of a pathogen. It is used to detect specific aquatic pathogens with high sensitivity and specificity like the White Spot Syndrome Virus (WSSV) and Viral Nervous Necrosis (VNN). This technology can be applied in disease surveillance by on-site testing of water and tissue samples of shrimp and fish farms. It decreases the time of disease detection and helps in prevention of disease outbreaks.

b. Biosensors (Fluorescence, SPR, Colorimetric)

The sensor can detect changes in the fluorescence, change in the refractive index (as in Surface Plasmon Resonance) or changes in visible color. It identifies pathogens or toxins at real time that are highly sensitive with high level of accuracy. This is used in hatcheries and diagnostic laboratories. In the context of biosecurity, it is essential in the early identification of malevolent microbes or toxins and thus reduced the risk of disease transmission and aids in proper preventive control in aqua culture systems.

c. Environmental DNA (eDNA/eRNA) Samplers

These samplers detect DNA or RNA fragments that are naturally exuded by organisms into the water surrounding without necessarily touching and disturbing fish. This method is applied to conduct regular monitoring of pond, cage, or hatchery water to detect viruses, bacteria or exotic pests that can pose a risk to the health of the stocks. Bio security wise, it offers a strong non-invasive surveillance tool which allows the early detection of pathogens.

d. Immunosensors / Lateral-Flow Test Strips

This sensor/ strip attaches certain antibodies to the antigens present in the pathogen and provides a visible band just like pregnancy test kits. It serves the purpose of facilitating easy, fast, and field based tests of pathogens without laboratory testing. It can be applied at farm level to prevent the spread of infections at an early stage. In biosecurity terms, this approach offers a quick and economical decision support to enable farmers to isolate or treat infected stocks.

e. Nanobiosensors

This sensor relies on nanomaterials like gold nanoparticles, carbon nanotubes, and quantum dots to enhance detection signals and sensitivity. It has high level of specificity for very low concentrations of pathogens or toxins. The technology is evolving in aquaculture to identify virus and harmful algal toxins. It has high accuracy and early surveillance of pathogens, thus enhancing biosecurity at the farm level.

2) Behavioral and Biomonitoring Sensors

Behavioral and biomonitoring sensors are equipment that keeps track and give real-time data of the activity, feeding and the physiological state of aquatic organisms. Thus, minimizing unnecessary handling, enhancing disease surveillance, and precision farming.

a. Underwater Cameras (optical sensors)

This uses waterproof video cameras which always record visual information and later processed with artificial intelligence or computer vision software to monitor feeding behavior, swimming, schooling, and external malformations on culture species in the ponds, cages, and recirculating aquaculture system (RAS) to streamline feed application, and identify early disease onset symptoms like lethargy or abnormal swimming. Biosecurity wise, it provides a non-invasive way of fish health check, with reduced handling and stress.

b. Biotelemetry Sensors (Implants/Tags)

A miniature sensor is placed into or onto the fish to broadcasts physiological or behavioral information about the fish like activity level, stress response, or heart rate (radio, acoustic, or satellite telemetry). It can be applied in broodstock management, aquaculture studies, and selective breeding programs to evaluate welfare, stress tolerance, and general performance. Biosecurity wise, these sensors identify the individuals or groups at risk early for isolating them and avoiding the disease transmission.

c. Toxic Gas Sensors (H_2S, CH_4)

The electrochemical or semiconductor sensors that identify, quantify, and make early alerts on some harmful gases like H_2S, CH_4 in water or air. These sensors are employed in aquaculture ponds and RAS to detect hazardous gases accumulation at an initial period, thus averting mass deaths.

3) Advanced / Next-Generation Sensors

Next-generation sensors provide predictive intelligence and automated command using IoT, AI, and machine learning to advance water quality, feeding methods and health of aquatic animals to improve aquaculture systems.

These sensors result in greater productivity, improved animal welfare, fewer risks of diseases, and sustainable farm management.

a. The Multiparameter Probes (CTD / Sondes)

These probes measure water quality parameters like conductivity, temperature, water pH, depth and DO. These are practically applicable in aquaculture ponds and in recirculation aquaculture systems (RAS). Biosecurity wise, the technology is important in monitoring water quality for healthy culture stocks.

b. Lab-on-a-Chip Biosensors

This miniaturized microfluidic-biosensors identify pathogens or biomarkers by chemical, optical, or electrochemical reactions. It is highly efficient and convenient to use in the field. Practically, this system is known to apply in the early detection of diseases within fish and shrimp farms enabling the farmers and technicians to detect infections before they spread extensively.

c. Portable qPCR-Based Sensors

It is used to test the presence of pathogens in a relatively short period in the farm. It is commonly applied in aquaculture systems to perform on-site testing to identify infectious agents at an early stage. Bio security- wise, this technique allows the rapid decision-making process whereby appropriate responses can be made in time to avoid disease outbreak (Endo et al., 2019, Farrell et al., 2021 & Bohara et al., 2022, Abdullah et al., 2024).

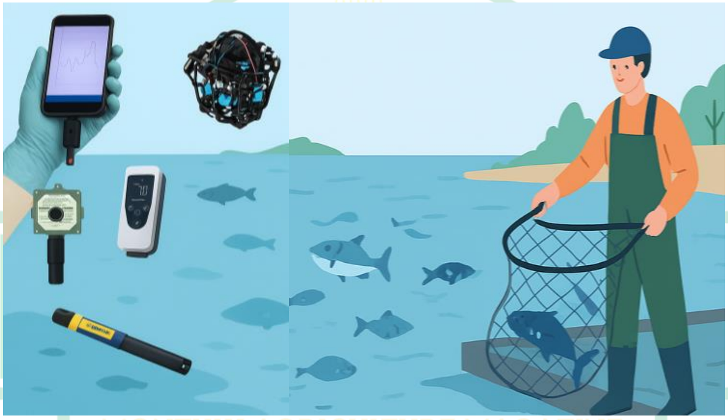

Fig.1 Sensors used in Aquaculture

Applications

Early-warning systems can be used in aquaculture, whereby sensors are deployed to identify water quality or behavior of fish and take preventive measures. Mapping of spatial sensor data enables treatment and biosecurity practices to be applied to the high-risk zones thereby lessening the overuse of chemicals. Mobile and fixed sensors at water inlets, feed lots assist in preventing the entry and cross-infection of pathogens. Quarantine monitoring with sensors covers water and environmental conditions of new batches or broodstock. Real-time microbial and chemical sensors are used to authenticate incoming sources of water. In addition, RFID and proximity sensors manage visitor and equipment tracking and the movements of humans and equipment and enhance record keeping.

Conclusion

Sensors are revolutionizing aquaculture disease control. The sensor technology has transformed the management of aquaculture disease prevention and biosecurity to make farms smarter, resilient, and environmentally friendly. The biosensors, eDNA, imaging, IoT and AI technology ecosystem are in the process of maturing, and the key to success lies in meticulous validation, maintenance, staff training, and proper analytics. The strategic implementation of these tools by farmers can help to improve the health of fish, safeguard the yields, and have sustainable aquaculture across the world.

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Revolutionizing Rural Finance: The Synergy of Fintech and Banking in India

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The financial services landscape in India is experiencing a seismic shift, propelled by the rapid rise of fintech startups that are redefining how financial products and services are delivered, particularly in underserved rural areas. These innovative, technology-driven companies have successfully captured a significant customer base by offering user-centric, efficient, and accessible solutions. However, FinTech companies often depend on traditional banks, both public and private for critical last-mile account services due to regulatory frameworks. Their unique approach to product and service delivery has attracted customers from diverse socio-economic backgrounds, expanding the financial market and fostering inclusion.

Traditional banks, in response, have embraced technological advancements to remain competitive, offering a range of products and services through digital platforms. To stay ahead in this dynamic market, banks are increasingly forming mutually beneficial partnerships with Fintech startups, leveraging their agility and innovation rather than reinventing the wheel. These collaborations combine the trust and regulatory expertise of banks with the technological prowess of Fintechs, creating a powerful synergy that enhances customer experiences, improves operational efficiency, and drives financial inclusion, especially in rural India.

This article explores into the revolutionary impact of Fintech inventions on the financial services landscape, with a specific emphasis on rural populations. It explores the developments in products, services, and processes offered by Fintech companies, their collaboration with banks, and their role in advancing financial inclusion. By examining key trends, technologies, and partnerships, this article aims to provide a comprehensive understanding of how fintech-enabled banking is reshaping India's financial ecosystem and empowering rural populations.

The Fintech-Bank Ecosystem- A Collaborative Approach: The financial services industry in India is undergoing a technological renaissance, with all players such as banks, Fintechs, and regulators, leveraging digital tools to deliver services efficiently. The Indian Government and banking sector have prioritized technology to address the needs of marginalized and underserved communities, aligning with the broader goal of financial inclusion. Public sector banks play a pivotal role in implementing Government policies, such as Direct Benefit Transfers (DBT) and the Aadhaar Pay Bridge System, which ensure seamless access to financial services with minimal response times.

Banks have historically shaped India's financial services landscape by spearheading the development of digital payment systems and infrastructure. The introduction of the Unified Payments Interface (UPI), mobile banking, and digital wallets has transformed how financial transactions are conducted. Fintech companies have built upon this foundation, introducing innovative payment solutions that cater to diverse consumer needs. Their customer-centric approach and technological agility have expanded the range of financial services available, particularly for underbanked and unbanked populations.

The collaboration between Fintechs and banks represents a "best of both worlds" strategy, blending innovation with trust. Fintechs bring cutting-edge technology and rapid product development, while banks offer regulatory compliance, infrastructure, and customer trust. This partnership has driven a significant increase in digital payments, fuelled by Government initiatives like Direct Benefit Transfer DBT, which facilitate wage and salary payments across organized and unorganized sectors. However, challenges remain, as cash continues to dominate due to the underdeveloped digital payment acceptance ecosystem, particularly in rural areas. Specialized institutions like Payment Banks and Small Finance Banks, licensed by the Reserve Bank of India (RBI), are addressing this gap by catering to low-value account holders, while business correspondent agents and Micro Finance Companies provide last-mile banking and lending services.

The Significance of Fintech in Rural Financial Inclusion: The rise of fintech companies has disrupted traditional financial models, introducing agility, innovation, and customer-centricity to the sector. These startups leverage advanced technologies such as artificial intelligence (AI), blockchain, and cloud computing to deliver fast, transparent, and accessible financial products. Their ability to rapidly conceive, develop, and launch groundbreaking solutions sets them apart from traditional banks, which often face bureaucratic hurdles.

India's fintech ecosystem is vibrant and diverse, with over 6,000 fintech companies, including more than 1,800 startups, as reported by the National Investment Promotion and Facilitation Agency (Invest India). Bengaluru and Mumbai host 42% of these firms, which target a wide range of products, customer segments, and regions. According to a Boston Consulting Group report, the Indian fintech market is projected to grow at an annual rate of over 35%, reaching $190 billion by 2030. The payments market alone is anticipated to generate $50 billion in revenue and $100 trillion in transaction volume by 2030.

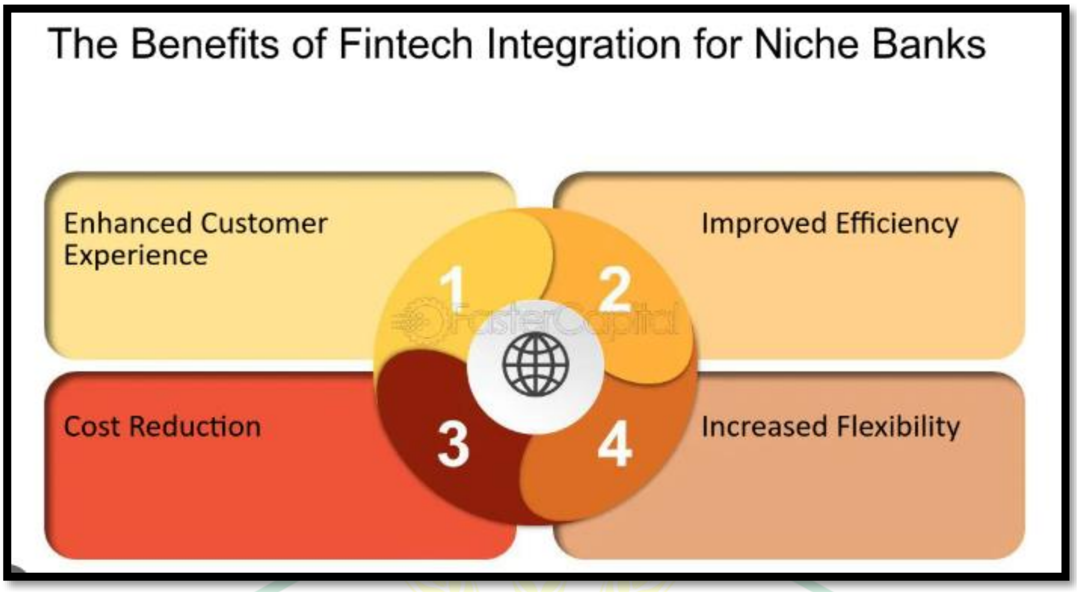
Fintechs are at the forefront of financial inclusion, particularly in rural areas, where traditional banking infrastructure is often limited. By offering small-value loans, digital payments, and insurance products, Fintechs cater to low-income and unbanked populations, including millennials and farmers. Their focus on niche markets and flexible, technology-driven solutions has enabled them to attract new customers and expand the financial market. However, regulatory constraints require Fintechs to partner with banks for last-mile services, such as account maintenance and compliance with RBI guidelines.

Traditional banks have responded to this disruption by adopting technology and forming strategic partnerships with Fintechs. These collaborations allow banks to enhance customer experiences, reduce operational costs, and reach underserved populations. By leveraging fintech innovations, banks can offer personalized products and services, compete with agile startups, and align with Government initiatives for financial inclusion.

Advantages of Fintech-Bank Integration in Agricultural Finance: The integration of fintech with banks is revolutionizing agricultural finance, addressing the unique challenges faced by farmers and rural communities. According to the Ministry of Agriculture and Farmer Welfare's 2023-24 report, approximately 56% of Indian farmers have accessed credit facilities, with only 69.6% of loans obtained from institutional bases like banks and cooperatives, whereas 20.5% originate from financiers. Over 59 million farmers lack proper access to financing, highlighting the immense potential for fintech-driven solutions in agribusiness and financial inclusion.

- **Improved Access to Finance**: Fintech-enabled banks provide farmers with easier access to credit, insurance, and other financial services, reducing dependence on informal moneylenders. By utilizing digital platforms, the processes of loan applications and disbursements are optimized, resulting in increased accessibility to financing for rural communities.
- **Enhanced Risk Management**: Data analytics and digital tools enable banks to assess and manage risks associated with agricultural lending, such as weather uncertainties and market fluctuations. Credit scoring models driven by AI increase precision and lower the rates of defaults.
- **Increased Efficiency**: Automation and digitalization streamline loan processing, disbursal, and repayment, reducing operational costs and improving productivity for both banks and customers.
- **Innovative Business Models**: Fintech integration allows banks to explore new models, such as platform-based banking and data-driven services, creating additional revenue streams and enhancing customer engagement.
- **Digital Financial Services: Driving Inclusion and Efficiency:** Digital financial services are transforming the financial landscape by expanding access, improving efficiency, and reducing costs.
- **Widened Reach**: Fintechs provide services to underbanked and unbanked communities, especially in rural areas with limited access to traditional banking infrastructure.
- **Greater Financial Inclusion**: By offering affordable, accessible financial products, Fintechs promote inclusion for marginalized communities, aligning with Government objectives.
- **Improved Delivery Efficiency**: Digital platforms enable faster and more efficient service delivery, reducing response times and enhancing customer experiences.

- **Enhanced Service Quality**: Technology-driven solutions offer personalized and user-friendly services, meeting the evolving needs of customers.



- **Improved Delivery Efficiency**: Digital platforms enable faster and more efficient service delivery, reducing response times and enhancing customer experiences.
- ✓ **Enhanced Service Quality**: Technology-driven solutions offer personalized and user-friendly services, meeting the evolving needs of customers.
- ✓ **Revenue Growth**: Fintechs and banks can tap into new market niches, driving revenue through innovative products and services.
- ✓ **Cost Savings**: Digitalization reduces branch and operational expenses, benefiting both businesses and customers.
- ✓ **Reduced Transaction Costs**: Digital payments and lending platforms minimize transaction fees, making financial services more affordable.

Fintech vs. Banks: A Comparative Analysis of Credit Delivery: The credit delivery process highlights the stark differences between traditional banks and fintech companies, particularly in serving rural and low-income customers. The below table illustrates a complete comparison:

Sl.No.	Credit Delivery Processes	Bank	Fintech Company
1	Location/Access	Branch Banking	Doorstep Banking
2	Accessibility and Acquisition of new customers	Walk-in Customers	Reaching their community dwellingsfor credit delivery
3	Transaction cost	High	Zero
4	Loan Limit	Min Rs. 25,000	Min Rs. 1,000
5	Pre / Post Inspection	Mandatory	Uses other Central Information Commission (CIC) related information
6	Repayment period	Minimum12 months	Ranging from 7 days to15 months
7	Repayment	Monthly/Quarterly/ Half yearly/Yearly	Daily/weekly/fortnightly/monthly
8	Documentation	Extensive	Mostly Digital

Sl. No.	Credit Delivery Processes	Bank	Fintech Company
9	Security/Collateral	Secured or covered under Credit Guarantee schemes	The major portfolio is unsecured
10	End use	Must be ensured	Self-certification digitally obtained
11	Ease of doing business	Complex	Diversified /Flexible
12	Technology for processing/sanction/disbursal, collection and recovery	LOS, LLMS, LMS, etc.	Online application is compulsory. App-based techno digital credit delivery model
13	Loan Delivery	2.-6 days	1 to 2 hours and even within 1 to 2 minutes if all the requirement fulfilled
14	Regulation	Highly regulated environment	Lighter and differential regulation, guidelines issued by RBI for digital lending recently
15	Coverage of area	Categorized area	Even remote corners
16	Recovery	Branch/BC Model, Agritech BC	Outsourced Collection Module with constant follow-up

This comparison underscores the agility and flexibility of Fintechs, which prioritize doorstep delivery, minimal documentation, and rapid processing. Banks, while offering robust infrastructure and regulatory compliance, often face higher operational costs and longer processing times, making Fintechs a preferred choice for small-ticket loans in rural areas.

Key Fintech Innovations Transforming Rural Finance: Fintech companies are leveraging advanced technologies to deliver innovative products and services tailored to rural customers. These developments are increasing efficiency, cutting expenses, and improving accessibility. Among the important technologies and their uses are:

App-Based Credit Delivery: Fintechs offer small-value loans starting at ₹5,000 with flexible repayment schedules (weekly or biweekly), reducing reliance on informal moneylenders. For example, farmers can access loans for equipment purchases with minimal documentation, ensuring compliance with regulatory requirements.

- **Cloud Computing**: It facilitates speedy disposition of end-to-end loan execution process without using expensive hardware. Private cloud solutions have helped Fintechs reduce expenses and scale operations efficiently, making financial services more accessible to rural customers.
- **Automation**: Automated systems streamline loan processing, enabling near-real-time decisions and fraud detection. Fintechs use preset decision rules to process applications in minutes, improving efficiency and consistency. For instance, credit ratings can be determined in under a minute, reducing the risk of fraud like money laundering.
- **Blockchain Technology**: Blockchain enables secure, transparent, and unalterable transactions, reducing costs and fraud risks. Fintechs like Khatabook, Propelled, and FIA Global use blockchain for services such as travel insurance, claim settlement, and e-KYC, enhancing trust and efficiency.
- **Artificial Intelligence (AI) and Cognitive Computing**: AI-driven tools, used by companies like Aye Finance and Bank Sathi, simplify credit underwriting and loan processing. Machine learning and analytics enable accurate risk assessment and personalized offerings, making loans more accessible to rural borrowers.
- **Robo-Advisors and Chatbots**: Vernacular chatbots and robo-advisors facilitate customer onboarding and support, particularly in rural and semi-urban areas. These tools use natural language processing to communicate in local languages, enhancing accessibility for micro, small, and medium-sized businesses.

- **Aadhaar-Based KYC and Biometrics**: Government initiatives like Jan Dhan Yojana, Aadhaar, and UPI have provided Fintechs with a robust platform for KYC compliance and digital transactions. Digital signatures, e-NACH, and e-stamps have accelerated adoption, enabling seamless last-mile services.
- **Social Scoring**: Fintechs are redefining creditworthiness by using alternative data sources, such as social media profiles, Swiggy order histories, and public records from the Ministry of Corporate Affairs and GST portal. This all-encompassing approach offers a thorough understanding of clients' financial behaviour and enhances traditional KYC.

The Role of Government Initiatives: Government programs have played a critical role in advancing financial inclusion and supporting fintech innovations. Initiatives like DBT, Aadhaar, and India Stack have made financial services more accessible, particularly in rural areas. The widespread adoption of smartphones has further enabled Fintechs to tap into previously underserved markets, offering credit and payment solutions to rural customers. The RBI's digital lending guidelines, introduced to promote transparency and consumer protection, ensure that Fintechs operate responsibly while fostering innovation.

The Future of Fintech-Bank Collaboration: The synergy between Fintechs and banks is a game-changer for India's financial ecosystem, particularly in rural areas. By combining Fintechs' technological agility with banks' regulatory expertise and infrastructure, these partnerships deliver superior services, enhanced security, and tailored solutions for small businesses and farmers. Fintechs provide innovative tools like agile loan management software and user-friendly apps, while banks offer insights into market trends and compliance, creating a robust framework for growth.

As Fintechs continue to innovate and banks embrace digital transformation, the financial sector is poised for significant expansion. These collaborations are unlocking new opportunities, improving the lives of rural communities, and contributing to a more sustainable and inclusive financial ecosystem. The integration of advanced technologies, such as AI, blockchain, and cloud computing, will further accelerate this transformation, ensuring that financial services reach even the most remote corners of India.

The notable partnerships between banks and fintech companies in India, focusing on remittances, payments, credit assessment, and financial inclusion. The below mentioned examples highlight collaborations that leverage technology to enhance financial services, streamline processes, and reach underserved populations, based on recent trends and initiatives in the Indian financial ecosystem.

- Through a co-lending approach, Federal Bank and Avanti Finance collaborated to offer rural, unserved, and underserved borrowers' economical loans by utilizing Avanti's tech-driven credit evaluation for rural borrowers.
- Ujjivan Small Finance Bank & Haqdarshak developed a financial literacy program to empower nano and MSME entrepreneurs, enhancing access to financial services in underserved communities.
- Spice Money's Adhikari network, combined with NSDL Payments Bank's to secure banking solutions, provides accessible financial services like payments and remittances in rural India.
- Since January 2021, ICICI Bank and Niyo have collaborated to issue tailored prepaid cards for MSME workers, streamlining digital payments and promoting financial inclusion.
- Kotak Mahindra Bank partnered with Pine Labs to enhance digital payment solutions for merchants, focusing on POS systems and UPI-based transactions.
- Axis Bank and Ezetap collaborated to provide digital payment solutions like mobile POS for merchants, facilitating seamless transactions for small businesses.
- SBM Bank and Lendingkart collaborated to provide digital lending solutions to MSMEs, leveraging AI-based credit assessment to bridge the credit gap.
- SBI plans to engage with 75-100 fintechs through Yono 2.0, focusing on payments, lending, and wealth management to enhance digital banking access.
- Federal Bank has teamed up with OneCard to provide co-branded credit cards aimed at digitally savvy customers, employing fintech-driven credit assessment.
- ICICI Bank, in Q1 FY24, issued more than 4.2 million credit cards in collaboration with Amazon Pay, increasing the use of digital payments.

- HDFC Bank invested in Cashfree Payments to integrate payment gateway solutions, supporting digital transactions for businesses and consumers.
- ICICI Bank acquired a stake in CityCash to enhance digital payment solutions for small businesses and underserved communities.
- RBL Bank partnered with Ongo to provide cashless transaction solutions, issuing bank cards to drivers and enabling digital payments for commuters.
- IDFC Bank collaborated with Capital Float to offer digital lending to small businesses with limited credit history, using alternative credit scoring.
- Yes Bank partnered with up to 36 fintechs for payments, digital lending, and customer service, focusing on digital acquisition and financial inclusion.

These partnerships reflect the growing synergy between banks and fintechs in India, driven by technologies like AI, machine learning, and UPI, as well as government initiatives like Pradhan Mantri Jan Dhan Yojana (PMJDY). They aim to enhance financial access, streamline payments, improve credit assessment, and promote inclusion, particularly for MSMEs, rural populations, and the underbanked.

Conclusion: The collaboration between Fintech startups and traditional banks is reshaping India's financial services landscape, particularly in rural areas. By leveraging cutting-edge technologies and innovative business models, Fintechs are addressing the needs of underserved populations, promoting financial inclusion, and driving economic empowerment. Banks, in turn, are enhancing their offerings through digital platforms and strategic partnerships, ensuring they remain competitive in a rapidly evolving market.

The future of finance is undeniably Fintech-enabled, with the potential to transform the lives of millions of farmers, small businesses, and rural communities. As India's fintech ecosystem continues to grow, projected to reach $190 billion by 2030, the synergy between banks and Fintechs will play a pivotal role in building a more inclusive, efficient, and sustainable financial system. By adopting these innovations, India is paving the way for a positive, more economically empowered prospectus for all its populace.

Sources:

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The Indispensable Strand: Unpacking the Multifaceted Benefits of Fiber Consumption

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Abstract: Dietary fiber, a complex carbohydrate derived from plant cell walls, has long been recognized for its crucial role in maintaining optimal human health. This technical paper delves into the diverse mechanisms by which fiber exerts its beneficial effects, encompassing its impact on digestive health, metabolic regulation, cardiovascular well-being, and immune function. We explore the distinct properties of soluble and insoluble fibers, discuss recommended daily intakes, and examine the implications of both adequate and insufficient fiber consumption. This review synthesizes current scientific understanding, highlighting the evolving research landscape and underscoring the indispensable nature of fiber in a balanced diet.

Keywords: Dietary fiber, gut microbiome, digestive health, metabolic syndrome, chronic disease prevention.

Introduction: A Dietary Cornerstone

For millennia, human diets have naturally included a significant proportion of fiber-rich plant foods. However, the advent of industrialized food processing has led to a widespread reduction in dietary fiber intake in many populations. This decline is increasingly recognized as a contributing factor to the escalating global burden of chronic diseases. Dietary fiber is defined as carbohydrate polymers with three or more monomeric units, which are neither digested nor absorbed in the human small intestine (Codex Alimentarius Commission, 2009). Beyond its basic role in promoting regularity, fiber's influence extends to a complex interplay with the gut microbiome, systemic metabolic processes, and overall disease prevention. This paper aims to provide a comprehensive overview of the current understanding of fiber consumption, emphasizing its critical importance for sustained health.

2. The Duality of Fiber: Soluble vs. Insoluble

Dietary fiber is not a monolithic entity; rather, it comprises a diverse group of compounds with varying physiochemical properties that dictate their biological effects (Anderson et al., 2009). The primary distinction is made between soluble and insoluble fibers, although many foods contain a mixture of both.

2.1 Soluble Fiber: These fibers dissolve in water to form a gel-like substance. Common sources include oats, barley, nuts, seeds, beans, lentils, and many fruits and vegetables. Soluble fiber's key attributes include:

- **Viscosity and Satiety:** The gel formed by soluble fiber can delay gastric emptying, leading to increased feelings of fullness and potentially reducing overall caloric intake (Slavin & Green, 2007). The viscosity of soluble fibers, such as beta-glucan at a concentration of 4%, is inversely correlated with the rate of glucose absorption (Brand-Miller et al., 2002).
- **Cholesterol Reduction:** Soluble fibers, particularly beta-glucan from oats and barley, can bind to bile acids in the small intestine, leading to their excretion. A comprehensive meta-analysis demonstrated that the consumption of soluble fiber is associated with an average reduction in LDL ("bad") cholesterol of approximately 4% to 5% (Brown et al., 1999). Specifically, consuming 3 grams per day of beta- glucan (the amount in one bowl of oatmeal) is linked to these effects.
- **Blood Sugar Regulation:** By slowing down the absorption of glucose, soluble fiber helps to stabilize blood sugar levels. Highly viscous fibers can reduce the postprandial glucose response by **up to 20%** (Brand-Miller et al., 2002).

- **Prebiotic Effects:** Many soluble fibers, such as inulin and fructooligosaccharides, are fermented by beneficial bacteria in the colon, acting as prebiotics that foster a healthy gut microbiome (Gibson et al., 2017).

2.2 Insoluble Fiber: These fibers do not dissolve in water and remain largely intact as they pass through the digestive tract. Found in whole grains, wheat bran, and the skins of many fruits and vegetables, insoluble fiber primarily functions as a "bulking agent":

- **Promotes Regularity:** Insoluble fiber adds bulk to stool, increasing its weight and softening its consistency, which facilitates easier passage and prevents constipation (Wald et al., 2008). Increased insoluble fiber intake can reduce whole gut transit time by 10% to 20% (Burkitt et al., 1972).
- **Digestive Transit Time:** By speeding up the movement of food through the digestive system, insoluble fiber can help prevent the accumulation of potentially harmful substances in the gut (Burkitt et al., 1972).
- **Diverticular Disease Prevention:** A high intake of insoluble fiber is associated with a reduced risk of symptomatic diverticular disease. A prospective study in men indicated that those in the highest quintile of fiber intake (averaging 28.9 g/day) had a 42 % lower risk compared to those in the lowest quintile (Aldoori et al., 1995).

3. Impact on Health and Disease Prevention

The comprehensive benefits of fiber consumption extend far beyond digestive comfort, playing a pivotal role in preventing numerous chronic diseases.

3.1 Digestive Health and the Microbiome:

The human gut harbors trillions of microorganisms, collectively known as the gut microbiome (Sekirov et al., 2010). Fermentation of fiber produces short-chain fatty acids (SCFAs), such as acetate, propionate, and butyrate, in a molar ratio often approximated as 60:20:20, respectively (Morrison & Preston, 2016). Butyrate is the preferred energy source for colonocytes and is critical for maintaining intestinal barrier function (Hamer et al., 2008). Increased prebiotic fiber intake has been shown to significantly elevate fecal SCFA concentrations, which correlates with anti-inflammatory effects in the colon (Kamada et al., 2013).

3.2 Cardiovascular Health:

Extensive epidemiological studies consistently demonstrate a strong inverse relationship between dietary fiber intake and the risk of cardiovascular disease (CVD) (Reynolds et al., 2013).

- **Risk Reduction:** A meta-analysis of prospective studies found that an increase of 7 g/day of **total fiber** intake was associated with a 9% lower risk of coronary heart disease and a lower risk of stroke (Reynolds et al., 2013).
- **Blood Pressure Regulation:** Higher fiber intake is associated with reduced blood pressure. Interventional trials have reported an average reduction in systolic blood pressure (SBP) of 2.5 mmHg and diastolic blood pressure (DBP) of 1.5 mmHg following high-fiber dietary interventions (Whelton et al., 2014).
- **Weight Management:** Fiber-rich foods improve satiety; studies on flaxseed fiber, for instance, showed a subsequent reduction in energy intake by over 10% at the next meal (Kristensen et al., 2012).

3.3 Metabolic Regulation and Diabetes:

Fiber intake is crucial for managing and preventing type 2 diabetes.

- **Glycemic Control:** High-fiber diets can reduce HbA1c levels, a key marker of long-term blood glucose control, by an average of 0.26 percentage points in patients with type 2 diabetes (Brand-Miller et al., 2002).
- **Type 2 Diabetes Risk:** A prospective cohort study indicated that individuals with the highest consumption of cereal fiber (median 7.5 g/day) had a 27 lower risk of developing type 2 diabetes compared to those with the lowest intake (median 2.0 g/day) (Salmeron et al., 1997; Lajous et al., 2013).

3.4 Cancer Prevention:

Adequate fiber intake is strongly associated with a reduced risk of colorectal cancer (CRC).

- **Colorectal Cancer Risk:** A large-scale meta-analysis demonstrated that an increase of 10 g/day in total dietary fiber was associated with a 10% reduction in the risk of CRC (Aune et al., 2011).
- **SCFA Effects:** Butyrate, a major SCFA, has been shown to induce cell cycle arrest and apoptosis in colorectal cancer cell lines at concentrations achievable in the colonic lumen, highlighting a critical protective mechanism (Hague et al., 1993).

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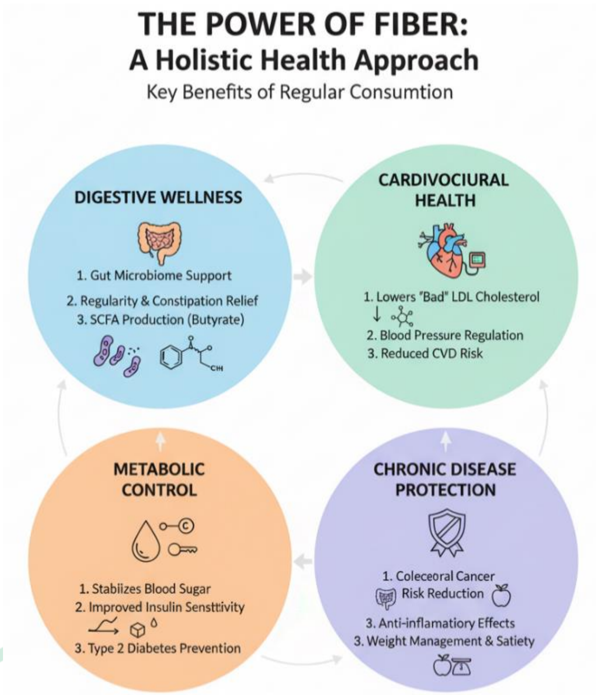

Figure: Info graphic summarizing the health benefits associated with regular fiber consumption
(Source: Scientific census & Research)

4. Recommended Intakes and Sources

Despite overwhelming evidence for its benefits, most individuals worldwide fail to meet recommended daily fiber intakes.

Authority	Age Group	Recommended Daily Fiber Intake
IOM (US) (2005)	Men (up to age 50)	38 g/day
IOM (US) (2005)	Women (up to age 50)	25g/day
SACN (UK) (2015)	Adults	30g/day (as Non-Starch Polysaccharides)

The reliance on processed foods means that the average intake in many developed countries often hovers around 15 to 18 g/day, representing a significant "fiber gap" (Dahl & Stewart, 2015).

Fiber content of selected food sources:

- **Legumes (e.g., Black Beans):** Approximately 15 g per one-cup serving.
- **Whole Grains (e.g., Whole Wheat Bread):** Around 2-4 g per slice.
- **Oats (Rolled, dry):** Approximately 8 **g** per half-cup serving, rich in β-glucan (Anderson et al., 2009).
- Adequate fluid intake (generally ≥2 Liters per day for adults) is mandatory when increasing fiber consumption to ensure smooth gastrointestinal transit and prevent constipation (Dahl & Stewart, 2015).

5. The Modern Fiber Gap and Future Directions

The "fiber gap" is a major public health challenge. The average intake in many developed countries is less than 60% of the recommended levels. Efforts to bridge this gap include food reformulation and the incorporation of isolated fibers. Clinical trials are currently assessing the impact of novel resistant starches and inulins on SCFA profiles and specific taxa within the gut microbiome, with the goal of developing personalized nutrition strategies (Dekkers et al., 2018). Further research is exploring the bidirectional communication of the gut-brain axis—a pathway heavily influenced by fiber derived SCFAs and its implications for managing stress and mood disorders (Cryan et al., 2019).

6. Conclusion

Dietary fiber is far more than just a digestive aid; it is a fundamental component of a healthy diet with profound implications for preventing a wide array of chronic diseases. Its multifaceted actions, from modulating the gut microbiome and regulating metabolism to lowering cholesterol and reducing cancer risk, underscore its indispensable nature. Addressing the prevalent fiber gap through dietary education and promotion of whole, unprocessed foods is a critical public health imperative. By prioritizing fiber consumption, individuals can significantly enhance their long-term health and well-being.

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Picea smithiana (West Himalayan Spruce): A Majestic Conifer of the Western Himalayas

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Introduction:

Picea smithiana is a very tall, evergreen conifer with a conical crown, horizontal or drooping branches and slender, pendulous, tassel-like branchlets ranging from 1 to 5 feet in length. The leaves are spirally arranged, acicular, 1-1.5 inches long and obscurely quadrangular with two lines of stomata on each of the four sides. The bark is grey to greyish-brown and exfoliates in small and thin scales; the wood is white, soft to moderately durable and used for planking, shingles, tea boxes and packing cases. It is also suitable for match and pulp production because of its long fibre. The species attains amazing dimensions, often exceeding 200 feet in girth.

Distribution and habitat:

P. smithiana has a natural distribution that stretches from Afghanistan to Kumaon, with elevations ranging from 7000-11000 feet (2100-3350 meters), occasionally descending to 5000 feet on cool aspects. The species grows in north and east-facing slopes, damp ravines and valleys, preferring deep, well-drained soils composed of mica-schist, shale, gneiss and limestone. Climatically, it belongs to the cool temperate zone of the Himalaya, with an annual precipitation ranging between 1000-2500 mm, majority of which falls as winter snow. The maximum temperature seldom rises beyond 32˚C and significant snowfall is usual between December and April. The spruce is typically found in mixed forests, often with *Abies pindrow, Cedrus deodara, Pinus wallichiana* and broad-leaved species including *Quercus dilatata, Q. semecarpifolia, Aesculus indica, Juglans regia* and *Prunus pardus.* In the understorey, *Taxus wallichiana* and *Vitis semicordata* are common associates.

Phenology:

Event	Period	Description
New shoot flush	April	Light green needles appear
Male flowers	April-May	Solitary, ovoid, yellowish-greenish, 1.5 cm long
Pollen shedding	Late April-Mid May	Wind-pollinated
Female cones (erect)	April-May	Reddish-green; become pendulous in June-July
Cone ripening	Oct-Nov	Cones turn brown, seeds released
Needle fall	May-June	3-6 years persistence

Good seed years are infrequent, occurring roughly once in every 5 years. Nutcrackers *(Nucifraga hemispila)* and flying squirrels destroy many unripe cones.

Germination:

Germination is epigeous, with the radicle emerging downward and the hypocotyl elongating, raising the cotyledons above the ground. The seed coat remains attached as a cap and eventually falls off, revealing 8-10 whorled cotyledons from which the new stem grows.

First year: The seedling develops a short, tapering primary root with few laterals, a thin green hypocotyl that becomes brown and 8-11 slender cotyledons measuring 0.7-1.1 inches long. The stem is short, bearing small acicular leaves on peg-like projections and a yellowish-grey terminal bud.

Second year: Roots become wiry and slightly longer, cotyledons may persist and new shoots emerge pale grey with spirally arranged leaves and forming axillary buds.

Third year: Lateral roots increase considerably, cotyledons wither and fall and the stem produces multiple-year shoots with bright green spirally arranged leaves and well-defined buds.

Growth during early years is extremely sluggish, about 1 inch per year for the first five years under natural conditions. In nurseries, seedlings can grow four feet in ten years. Spruce is susceptible to drought, thriving only on moist, shaded microsites, yet is frost-hardy in its native range.

Methods of propagation:

Natural regeneration- Long intervals of good seed years is a limiting factor. Under natural conditions, germination begins about end of May, and may continue during July-August. Chief requirements for successful regeneration are: freshly exposed and porous mineral soil, absence of felling debris, freedom from heavy weed growth, protection from fire and grazing and plenty of overhead light with side shade. A thorough clearing of ground by means of controlled fire is beneficial. Natural regeneration has to be weeded and tended for its successful establishment. Silver fir and spruce forests are usually worked and managed together, for exploitation and regeneration.

Artificial regeneration- Spruce can be raised by direct sowing in well worked patches, at the break of rains after clearing the debris and raw humus. Since the growth of seedlings is slow, results are doubtful; direct sowings are, therefore, seldom carried out on an extensive scale.

Planting out of nursery-raised seedlings, 3 years old, about 23 cm tall (sometimes even 2 or 4 years old), or raised in polythene bags, are planted out during monsoon rains, in pits 30 cm^3, dug up in advance of planting season, under suitable opened canopy, after removing humus and clearing undergrowth. Plants are spaced about 3 m × 3 m, and staked.

Nursery practice:

Spruce nursery should be established at altitudes ranging from 2300-2600 meters on a sheltered aspect. Seed is sown during the rainy season. One year old seedlings are pricked out to transplant beds and spaced 7.5 cm apart in 15 cm rows. They are pricked out again at 2 years old, after rains, around 15 cm apart in lines 22.5 cm apart. Seedlings are ready for planting out in rains when they are 3 years old and about 23 cm in height. Sowing may be done even in Oct-Nov (before snowfall) but germination will commence only in May-June. Care should be taken not to harm the roots or expose them to sunlight during transit; plants should be bundled together with roots wrapped with wet moss.

Seedlings can also be raised by sowing directly in polythene bags, 3-4 seeds in each and subsequently singling them out if more than one seed germinate; or as an alternative, one year old seedlings may be pricked out from nursery beds into polythene bags instead of transplant beds.

Tending:

Plants must be kept properly weeded in regeneration areas, for the first 5-7 years till they are well established.

Injuries, pests and diseases:

Injuries- Grazing damages the seedlings by trampling and uprooting them along with grass, etc. Goats browse young shoots, but avoid it if other fodder is available. If and when fire occurs in spruce forests, it causes heavy damage. It is liable to wind-throw; and snow-bending in sapling stage. It is frost-hardy.

Insects- Pseudo-cones are formed by aphids, *Chermes abietispieoe*, in the green state in May and June, with pseudo-scales with sharp points (the aborted needles), in regular spirals.

Fungi- No serious fungal infections have been reported in *P. smithiana*. *Trametes pini* is found on lopped spruce but does not cause much damage. *Peridermium thomsoni* infects the needles and green cones; this fungus is neither common nor serious. *Barclayella deformans* produces short orange-tassels, 3-5 cm long. *Peridermium piceae* is a rust fungus which attacks young shoots.

Uses:

Local medicinal uses- *Picea smithiana* has traditionally been used to treat asthma, diarrhea, TB and diabetes (Wali et al. 2019). Its resin is commonly used to treat cuts, sores, joint discomfort, stomach ache, wounds and cracked heels (Malik et al. 2015). The species is also used to cure rheumatism, kidney stones and heat-related conditions. Powdered cones combined with hot water ease chest discomfort, while heated resin applied externally treats skin boils and cracks (Rokaya et al. 2010). Phytochemicals in *P. smithiana* have high antibacterial, antifungal, antimicrobial, antiproliferative and cytotoxic properties. Essential oils extracts, ethyl acetate, ethanol and acetone have been shown to have significant effects against bacterial strains such as *Micrococcus luteus, Bacillus subtilis* and *Pseudomonas alcaligenes* as well as fungi such as *Bipolaris spicifera* and *Curvularia lunata* (Verma and Nailwal 2018; Ali et al. 2020). Essential oils are also utilized to treat catarrhal illnesses in children and to alleviate rheumatic and neuralgic pain (Pauli and Sclicher 2004). Flavanonols such as quercetin, dihydroquercetin and dihydromyricetin inhibit urease (Bashir et al. 2017). Certain phytochemicals have cytotoxic and phytotoxic properties against human tumor cells, such as monocyte (THP-1), lung (A-549), liver (HEP-1) and ovarian (IGR-OV-a) cancer (Shah and Dar 2014; Ahmadi et al. 2019).

Local food uses- The young male catkins are used as a flavoring ingredient, whilst the mature female cones, particularly their core region, are sweet and syrupy. The powdered inner bark serves as a thickening agent in soups and is used with grains to make bread. Additionally, a refreshing tea is brewed from the young shoot tips.

Local handicraft and other uses- The gum is traditionally used to mend cracked pots and remove hair (Wali et al. 2019). Its wood is valued for a variety of applications, including construction, railway sleepers, cabinetry, packing cases, wood pulp, shingles and crates (Jan et al. 2009). The bark, which is noted for its high-water resistance, is often used in roofing and water trough construction, while the leaves are woven into mats (Ali et al. 2018). Essential oils from the species are used in room sprays and deodorants (Conifer Specialist Group 1998). Furthermore, *P. smithiana* sawdust has been demonstrated to effectively adsorb heavy metals including lead, chromium and cadmium by bio-adsorption (Mahmood-Ul-Hassan et al. 2018).

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Price Volatility in Agricultural Markets: Causes, Impacts, and Solutions

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Abstract

Agricultural markets are inherently volatile, with prices often fluctuating due to a range of climatic, economic, and policy-related factors. Price volatility poses significant challenges for farmers, consumers, and policymakers alike, affecting income stability, food security, and investment in the agricultural sector. The unpredictability of agricultural prices stems from both domestic and global influences such as weather anomalies, changing trade dynamics, input cost variations, and speculative trading. This article explores the underlying causes of agricultural price volatility, examines its socio-economic impacts, and discusses potential strategies for stabilization and resilience-building. Solutions such as improved market intelligence, crop diversification, value chain integration, and effective policy interventions can mitigate volatility and promote sustainable agricultural growth.

Keywords: Agricultural Prices, Market Volatility, Food Security, Risk Management, Price Stabilization, Value Chain, Policy Intervention, Climate Change, Commodity Markets, Trade Dynamics

Introduction

Agriculture remains the backbone of most developing economies, providing livelihood for millions and ensuring food security for the global population. However, agricultural markets are characterized by high levels of price volatility due to their dependence on natural conditions and external market forces. The unpredictability of prices has become more pronounced in the era of globalization and climate change, making it a persistent concern for producers, consumers, and governments.

Price volatility in agriculture refers to large and unpredictable fluctuations in the prices of agricultural commodities over a short period. While some degree of fluctuation is normal and even necessary for efficient markets, excessive volatility can destabilize incomes, reduce investments, and heighten food insecurity. The challenge lies in understanding the complex web of factors driving volatility and in implementing strategies to cushion its impacts.

Causes of Price Volatility in Agricultural Markets

1. Climatic Variability and Natural Disasters

Weather plays a decisive role in agricultural production. Droughts, floods, cyclones, and unseasonal rains can drastically affect yields, leading to sharp supply shocks. For example, the 2023 El Niño phenomenon disrupted monsoon patterns across South and Southeast Asia, reducing rice and maize yields and triggering global price hikes. Climate change is intensifying the frequency and severity of such events, amplifying production uncertainty.

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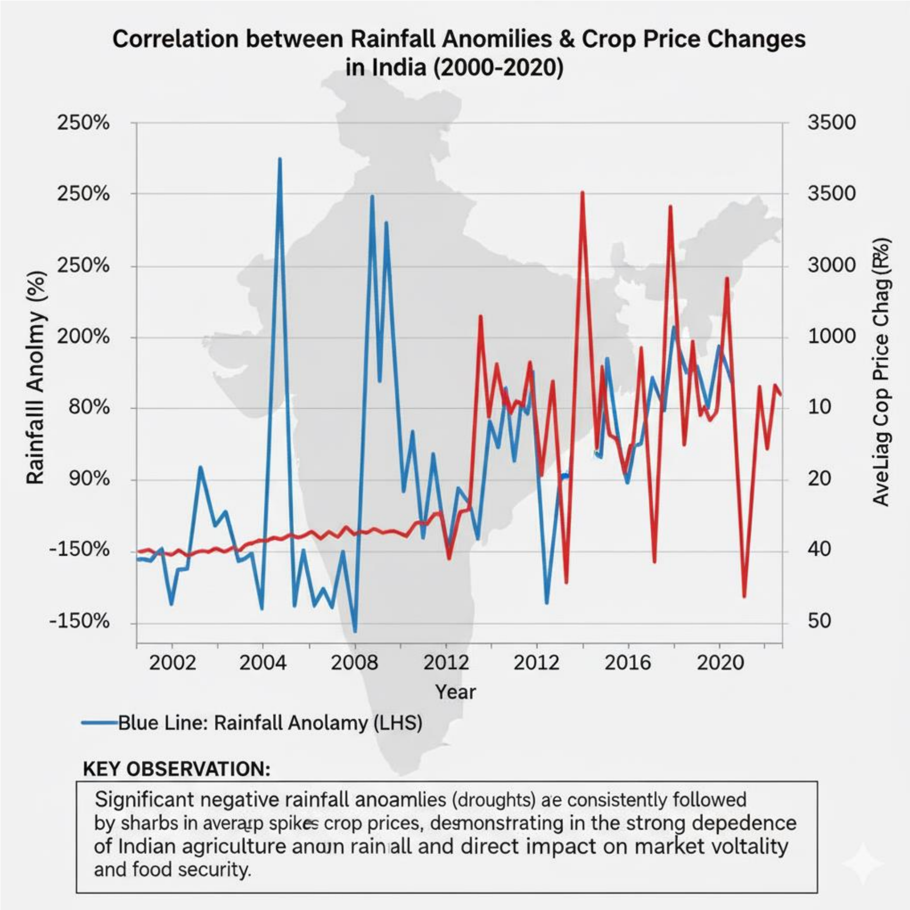


2. Supply and Demand Mismatch

Agricultural supply chains often lack flexibility. Crops cannot be rapidly increased or decreased in response to market demand because production cycles are long and dependent on seasons. A bumper harvest may lead to glut and price crashes, while a failed monsoon or pest outbreak can cause scarcity and price surges. Rapid urbanization and changing consumption patterns also alter demand for food commodities, adding further instability.

3. Global Trade and Market Integration

With globalization, domestic agricultural prices are increasingly influenced by international market trends. Export bans, import duties, and global stock levels of major crops such as wheat, soybeans, and rice directly impact local prices. The 2007–2008 global food crisis, for instance, was partly triggered by export restrictions imposed by key grain-producing countries, leading to a 45% rise in global food prices within a year.

4. Policy Uncertainty and Government Interventions

Frequent policy changes such as sudden export bans, changes in Minimum Support Prices (MSPs), or unpredictable procurement practices can create uncertainty in the market. While such measures are often taken to protect domestic consumers, they can destabilize farmer income and market expectations. Inconsistent policy interventions also discourage private investment in storage and supply chains.

5. Rising Input Costs

Fertilizers, fuel, and labour costs significantly affect the cost of agricultural production. Sudden hikes in fuel or fertilizer prices often linked to global energy markets can push up production costs, which are then reflected in commodity prices. For example, the post-COVID surge in global fertilizer prices in 2022 led to sharp increases in the cost of rice and maize cultivation.

6. Speculative Trading and Market Manipulation

Commodity futures and derivatives markets were developed to hedge risk but sometimes contribute to volatility. Excessive speculative activity by non-commercial traders can artificially inflate or deflate prices beyond what fundamentals justify. Though India's commodity markets are regulated, speculative pressures remain a factor, especially for commodities like guar, cotton, and pulses.

7. Post-Harvest Losses and Infrastructure Gaps

Inadequate storage, poor logistics, and insufficient cold chain infrastructure lead to massive post-harvest losses estimated at 15–20% for perishables in India. These losses distort effective supply and contribute to unpredictable market behaviour. The lack of farmer access to timely price information further worsens the issue.

Impacts of Price Volatility

1. Impact on Farmers' Income and Livelihoods

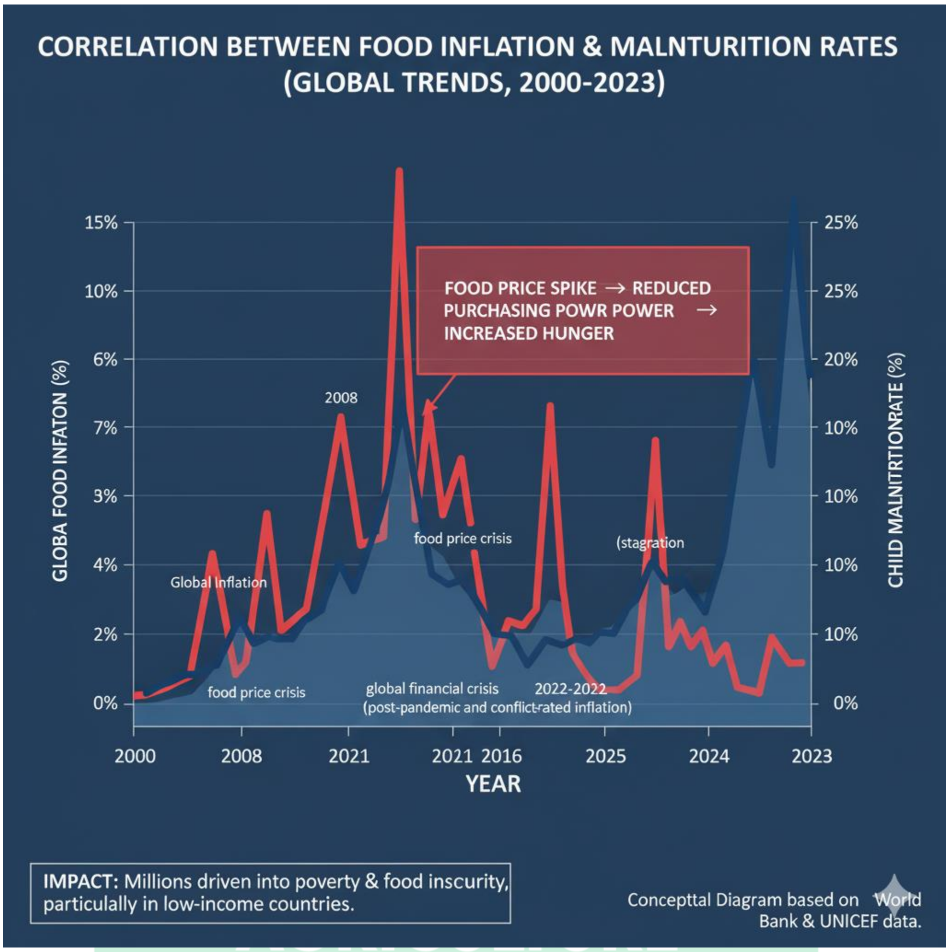
Farmers bear the brunt of price volatility. When prices fall below production costs, their earnings plummet, leading to indebtedness and distress sales. Price crashes in commodities like onions and tomatoes have repeatedly affected small farmers in India. Conversely, price surges benefit traders and intermediaries more than producers, as farmers often sell immediately after harvest at low prices.

2. Food Security and Consumer Welfare

Volatile food prices have a direct bearing on food security, particularly for low-income consumers. Price spikes in staple foods like wheat, rice, or pulses can lead to malnutrition and social unrest. During the 2020 pandemic, supply chain disruptions caused significant food inflation in several developing countries, disproportionately affecting urban poor households.

3. Investment and Production Decisions

Uncertain price trends discourage long-term investments in agriculture. Farmers hesitate to adopt improved technologies or diversify crops if they cannot predict returns. Similarly, agribusinesses delay investments in processing or storage when future market conditions are unclear, impeding value addition and rural development.



4. Macroeconomic and Fiscal Stability

At a national level, high agricultural price volatility can affect inflation, fiscal stability, and trade balances. Governments often respond to price surges through subsidies, import liberalization, or public distribution measures—all of which strain public finances. Conversely, low prices can lead to demands for farm loan waivers and higher MSPs, further adding fiscal pressure.

5. Social and Political Consequences

In countries where a majority depend on agriculture, price volatility can spark social unrest. Farmer protests, food riots, and political instability have historically been linked to sharp price movements. Managing agricultural prices is therefore not only an economic priority but also a social necessity.

Strategies and Solutions for Reducing Price Volatility

1. Strengthening Market Information Systems

Timely and transparent information helps all market participants make better decisions. Platforms like India's Agmarknet and e-NAM (National Agriculture Market) provide price and supply data across markets, helping farmers choose when and where to sell. Expanding such systems and integrating them with AI-based price forecasting tools can significantly reduce information asymmetry.

2. Promotion of Storage and Warehousing Infrastructure

Investment in scientific warehousing, cold storage, and rural logistics is essential to stabilize supply. Farmers should have access to negotiable warehouse receipts, allowing them to store produce during gluts and sell later when prices improve. Public-Private Partnerships (PPPs) can help expand modern storage capacity, reducing wastage and panic selling.

3. Crop Diversification and Value Addition

Encouraging farmers to diversify from staple grains to high-value crops (like pulses, oilseeds, and horticulture) reduces dependence on a single commodity and spreads risk. Value addition through agro-processing also

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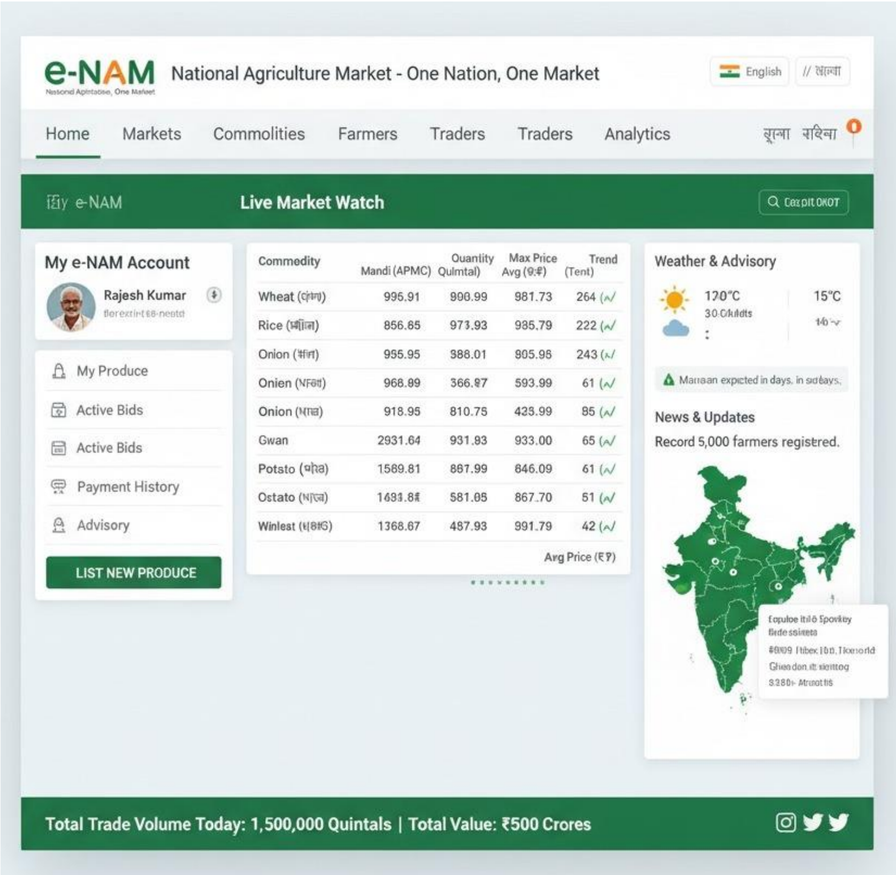
provides income stability. For instance, tomato processing into puree or chilli drying can protect farmers from market crashes.



Screenshot or infographic of the e-NAM digital trading platform.

4. Weather and Price Risk Insurance

Agricultural insurance schemes like the Pradhan Mantri Fasal Bima Yojana (PMFBY) can protect farmers from weather-induced losses. Complementary price insurance mechanisms or income support programs can shield them from extreme price declines. Linking these schemes with real-time satellite and IoT data can improve accuracy and reduce claim delays.

5. Regulating Speculative Activities

While futures markets are vital for price discovery, regulators like SEBI must ensure transparency and prevent excessive speculation. Introducing position limits, enhancing market surveillance, and promoting hedging by genuine stakeholders can balance efficiency with stability.

6. Policy Consistency and Predictability

Stable and transparent policies on trade, MSPs, and subsidies are crucial. Governments should avoid sudden export bans or import duty changes, which send mixed signals to markets. Long-term procurement and buffer stock policies can also cushion supply shocks without distorting market behaviour.

7. Enhancing Global and Regional Cooperation

Global price stabilization requires coordinated international efforts. Regional food reserves, transparent trade policies, and early warning systems can mitigate the impact of supply shocks. India, for example, can play a leading role in establishing a South Asian Food Security Mechanism to manage cross-border commodity volatility.

Conclusion

Price volatility in agricultural markets remains a complex and persistent challenge shaped by climatic, economic, and policy factors. While complete elimination of volatility is neither feasible nor desirable, its adverse impacts can be mitigated through proactive and integrated approaches. Strengthening infrastructure, enhancing information systems, stabilizing policies, and promoting risk management instruments can collectively build resilience. In the long run, empowering farmers with knowledge, technology, and market access will ensure that agricultural growth remains inclusive, stable, and sustainable.

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The Blood Berry-The Anti-Hemorrhagic Potential of Karonda

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Introduction

Nature has long been humanity's pharmacy, offering countless medicinal plants that continue to surprise scientists and healers alike. Among these treasures lies Karonda (*Carissa carandas* L.), a hardy, thorny shrub that produces small, dark-pink to purple fruits known for their tangy flavor and potent medicinal properties. Though commonly used in pickles, jams, and chutneys across India, Karonda's therapeutic value goes far beyond its culinary uses.

One of its most remarkable and lesser-known health benefits lies in its ability to control and prevent hemorrhage a condition involving excessive bleeding either externally or internally. Traditional healers and Ayurvedic practitioners have long relied on various parts of the Karonda plant, especially the fruit and leaves, for treating blood disorders, wounds, and hemorrhagic conditions. Modern research is now beginning to validate these ancient claims, making Karonda a promising natural agent in the management of bleeding-related ailments.

Botanical Identity and Distribution

Karonda belongs to the family Apocynaceae and is scientifically known as Carissa carandas L. It is a drought-tolerant, evergreen shrub native to India and Sri Lanka, and it thrives in arid and semi-arid regions. The plant is also found in Pakistan, Nepal, Myanmar, Malaysia, and parts of Africa, and has naturalized in tropical and subtropical regions worldwide.

In India, Karonda grows abundantly in the Western Ghats, the sub-Himalayan tracts, and the Deccan plateau. It is known by various regional names: Karaunda in Hindi, Kalakai in Tamil, Karamcha in Bengali, Karanda in Marathi, and Koromcha in Assamese. The shrub bears glossy green leaves, white star-shaped flowers, and berry-like fruits that turn from green to red, then deep purple upon ripening. Its hardiness, low maintenance, and multipurpose use make it a valuable crop in home gardens and dryland farming systems.

Traditional and Medicinal Uses of Karonda

Karonda has been used for centuries in Ayurveda, Unani, and folk medicine systems for a wide variety of health problems. Traditionally, the fruit, leaves, roots, and latex of Karonda are employed for the following:

- **Fruits**: Used to treat anemia, scurvy, and diarrhea; also as an appetite stimulant and cardiotonic.
- **Leaves**: Applied as poultices on wounds, skin infections, and insect bites.
- **Roots:** Used in traditional medicine for fever, stomach disorders, and as a vermifuge.
- **Latex:** Used to stop bleeding from cuts and wounds.

Among these applications, its anti-hemorrhagic properties stand out prominently. The plant is considered a natural blood purifier and blood coagulant, capable of accelerating the clotting process and reducing bleeding tendencies.

Understanding Hemorrhage and the Need for Natural Remedies

Hemorrhage refers to the escape of blood from blood vessels due to injury, disease, or internal ruptures. It can occur externally or internally. Severe hemorrhage can lead to anemia, shock, or even death if not controlled promptly.

In conventional medicine, hemorrhage is managed using surgical interventions, hemostatic agents, and blood transfusions. However, in mild to moderate cases such as gum bleeding, nosebleeds, menstrual bleeding, or internal microbleeds natural remedies with clot-promoting and vasoconstrictive properties can be highly beneficial. Karonda has been historically recognized for such effects, providing a safer, affordable, and readily available option for people in rural and resource-limited settings.

Phytochemical Constituents Responsible for Anti-Hemorrhagic Action

Karonda's medicinal value is attributed to its rich phytochemical composition, which includes:

- **Tannins** – Promote blood clotting by precipitating proteins and constricting blood vessels.
- **Flavonoids** – Strengthen capillary walls and prevent bleeding.
- **Vitamin C** – Essential for collagen synthesis and tissue repair.
- **Iron –** Helps in red blood cell regeneration.
- **Saponins and Alkaloids** – Exhibit anti-inflammatory and antimicrobial activities.
- **Phenolic compounds** – Act as antioxidants and contribute to faster tissue recovery.

These compounds work synergistically to enhance clot formation, strengthen blood vessels, and promote healing of tissues, making Karonda a potent anti-hemorrhagic fruit.

Karonda in Ayurvedic Perspective

In Ayurveda, Karonda is classified under the category of "Raktastambhaka dravyas" substances that arrest bleeding. It is considered to have Kashaya (astringent) and Tikta (bitter) tastes, with Ruksha (dry) and Sheeta (cooling) qualities.

According to Ayurvedic principles, these properties make it effective in pitta dosha disorders, particularly those involving excessive heat and bleeding, such as:

- Raktapitta (Bleeding Disorders)
- Rakta (Heavy Mensural Bleeding)
- Twakrogas (Skin ailments involving oozing or bleeding)

Karonda fruit juice and leaf extracts are traditionally prescribed for nosebleeds, bleeding gums, piles, and uterine hemorrhage.

Scientific Validation of Karonda's Anti-Hemorrhagic Potential

Modern pharmacological studies have begun to substantiate Karonda's traditional uses. Research indicates strong antioxidant, anti-inflammatory, antimicrobial, and hemostatic properties.

1. **Hemostatic and Astringent Action** – Tannins in Karonda minimize blood loss by constricting blood vessels.
2. **Wound-Healing Activity** – Topical application accelerates wound contraction and pithelialization.
3. **Antioxidant and Anti-inflammatory Role** –Flavonoids neutralize free radicals and reduce inflammation
4. **Role of Vitamin C and Iron** – Strengthen capillary walls and improve hemoglobin levels.
5. **Potential Use in Gynecological Disorders** – Decoction helps manage excessive menstrual bleeding.

Conclusion

Karonda (*Carissa carandas* L.) is a remarkable example of how traditional plants can bridge the gap between ancient wisdom and modern medicine. Its potent combination of tannins, flavonoids, vitamin C, and iron provides a strong foundation for its anti-hemorrhagic and wound-healing properties.

Rediscovering such natural remedies is both sustainable and health-promoting. Whether consumed as a fruit, applied as a paste, or used in herbal formulations, Karonda stands out as a natural guardian against bleeding disorders and a valuable addition to the medicinal plant repertoire.

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Back to Our Roots: Therapeutical potential India's Traditional Rice Varieties

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Introduction

Rice is the leading cereal crop cultivated worldwide. More than two-third of the world's population relies on rice as a primary source of staple food (Tyagi *et al.*, 2004; Bhat and Riar, 2015). Rice is the principal crop in India and is characterized by significant genetic diversity with thousands of varieties. Its cultivation makes the backbone of agricultural activity and supports the livelihoods of millions (Rathna Priya *et al.*, 2019). Traditional rice varieties, often referred to as folk rice varieties, exhibit wide variation in colour, taste, grain size, aroma, and growth period. They have been cultivated widely throughout India's diverse agro-ecological zones. Thousands of traditional rice varieties existed before the Green Revolution, but most were subsequently replaced with high-yielding varieties (HYVs). Historical records in the Ayurvedic Treatise (Indian Materia Medica) mentions several traditional Indian varieties recognized for their healing and therapeutic properties (Das and Oudhia, 2000; Deb, 2014).

Popular Indian traditional rice varieties

India is the land of rich agricultural heritage, particularly in rice cultivation. India's diverse agro-ecological regions, from coastal lowlands to Himalayan highlands, support thousands of indigenous rice varieties **(Table 1)**.

Table 1. List of traditional rice varieties cultivated in India

S.No.	State	Traditional rice varieties
1.	Tamilnadu	Karungkuruvai, Kattuyanam, Kuzhiadichan, Kullakar, Mappillai samba, Thooyamalli,
2.	Kerala	Njavara, Pokkali, Pavizham
3.	Manipur	Chakhao, Hamei
4.	Assam	Joha, Bhola
5.	Chhattisgarh	Jeeraphool, Bamboo rice
6.	Uttar Pradesh	Kalanamak, Neta
7.	Gujarat	Kolam rice
8.	Karnataka	Sona masoori, Kagga, Gowri sanna
9.	Punjab	Tulaipanji, Sugandha, Sharbati
10.	West Bengal	Gobindobhog rice, Kalonunia rice

Importance of traditional rice varieties

India's rich agricultural legacy is reflected in its traditional rice varieties, which provide significant nutritional, medicinal, and cultural value (Deb, 2014; Borah *et al.*, 2018).

1. Nutritional richness
2. Therapeutical and medicinal value
3. Climate resilience
4. Pest and disease resistance
5. Suitability for organic farming
6. Support diversity
7. Cultural and heritage significance
8. Economic and market potential

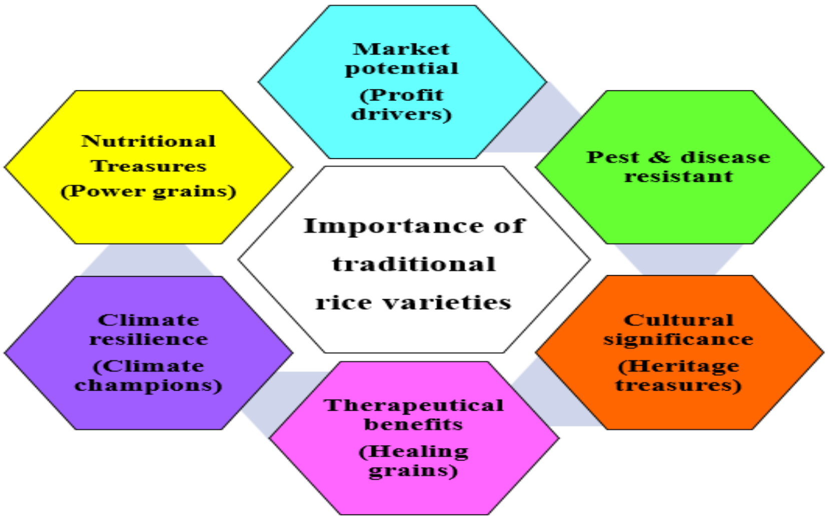

Figure 1. Importance of traditional rice varieties

Medicinal properties of traditional rice varieties

Among India's agricultural treasures, traditional rice varieties valued for their notable nutritional and medicinal properties. People select rice varieties according to their nutritional and health benefits.

1) Karungkuruvai

Karunkuruvai rice, characterized by its dark colour, is a traditional Tamil Nadu variety. It is prized in Siddha medicine for its high content of protein, fat, phosphorus, fiber, and antioxidants. Its medicinal application in treating skin ailments, urinary tract diseases and venomous stings (Pushpam *et al.*, 2019; Ashraf *et al.*, 2024).

2) Njavara

Njavara is a traditionally grown rice variety in upland, semi-arid, and drought-prone areas of Kerala. It exhibits low yields, moderate resistance to pests, and husks that vary from golden yellow to dark brown. In Ayurvedic practice, Njavara addresses circulatory, respiratory, digestive, and musculoskeletal conditions, such as arthritis and nerve-related problems. Njavara kizhi, a poultice made from rice, milk, and herbs, enhances blood circulation and relieves joint stiffness (Deepa *et al.*, 2009).

3) Chakhao

Chakho (black rice) is one of the traditional aromatic rice landraces from Manipur in North-East India. Chakhao, meaning "delicious rice" (Chak = rice; ahaoba delicious) in the Manipuri language. Widely cultivated in the valley and hill districts of Manipur under traditional practices. The major ethnic community of Manipur (Meiteis) believes chakhao rice holds cultural significance, used in rituals, festivals, and traditional delicacies. Pregnant women are traditionally served this rice to support childbirth, and it also serves as a natural remedy for diabetics. It is rich in anthocyanins, vitamins, minerals, and antioxidants, and anticarcinogenic properties it offers significant health benefits and therapeutic value (Roy *et al.*, 2014; Borah *et al.*, 2018).

4) Jeeraphool

Jeeraphool rice, a native aromatic variety grown in Chhattisgarh particularly the Surguja district. It is known for its distinctive cumin-shaped grains and flavorful culinary properties. Easily digestible, it promotes digestive health and, being rich in protein, fiber, iron, zinc, and manganese, boosts nutrition and immunity. Its moderate amylose content supplies steady energy and reduces tiredness. (Singh *et al.*, 2021; SWAHIndra).

5) Kalanamak

Kalanamak, an aromatic heritage rice from northeastern Uttar Pradesh. It is valued by the local population as superior to the renowned Basmati rice of India. It is a salt-tolerant black rice variety. It is utilized to address skin disease treatment and blood pressure regulation. It is characterized by a low glycemic index, which is ideal for diabetics, helps in slow digestion, and controls blood sugar levels. (Pushpam *et al.*, 2019; Chaudhary *et al.*, 2021; Mishra *et al.*, 2023).

Conclusion

Traditional or folk rice varieties preserve a wealth of genetic, cultural, ecological, and medicinal wisdom. Many of them are rich in nutrients and offers medicinal benefits. Conserving these traditional varieties is essential for ensuring future food and nutritional security, promoting climate resilience, preserving biodiversity, and safeguarding the natural health benefits they offer to communities. Future research should focus on the medicinal aspects of traditional rice varieties with exploring the bioactive compounds can help in developing functional food that supports health, prevent diseases, and strengthen the connection between traditional diets and modern nutrition science.

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Shining Opportunities Beneath the Water – The Rise of Pearl Farming

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Queen of Gems

Pearls, known as the gem of the sea are exquisite natural creations formed by marine oysters and freshwater mussels. They are renowned for their brilliant sheen and smooth texture and appear in a wide range of attractive colours, making them symbols of elegance and purity.

Classification of Pearls

Pearls can be classified based on their source and nature.

I. Based on Source

Pearls are primarily categorized into two major types: freshwater pearls and saltwater (marine) pearls, depending on the habitat of the mollusks in which they are formed.

Type of Pearl	Species	Major Pearl-Producing Regions in India
Freshwater Pearls	*Lamellidens marginalis*, *L. corrianus*, *Parreysia corrugata*	Kashmir, Hyderabad, Tamil Nadu
Saltwater Pearls	*Pinctada fucata*, *Pinctada margaritifera*	Gulf of Mannar, Gulf of Kutch, Palk Bay Strait, Andaman & Nicobar Islands

II. Based on Nature

Pearls are further classified into natural, cultured and artificial types based on their formation process.

- **Natural Pearls:**
  These pearls are formed naturally when a foreign particle accidentally enters the mantle tissue of a mussel or oyster, stimulating the secretion of nacre around it.
- **Cultured Pearls:**
  Cultured pearls are produced by artificially introducing a nucleus (foreign particle) into the oyster or mussel tissue, which induces nacre secretion. This method is widely practiced and accounts for the majority of pearl production globally, including India.
- **Artificial Pearls:**
  These are man-made imitations created from materials such as marble, glass, shell beads, plastics or ivory. They are coated with pearl essence, a mixture of silvery extract from fish scales and enamel, to mimic the luster of natural pearls.

Pearl Formation:

Pearl cultivation, also known as pearl farming, is a lucrative aquaculture business that involves the production of pearls through the cultivation of oysters and mussels. It is the process of producing pearl by implanting bead into mollusk tissue through which oyster is stimulated to produce layers of nacre to form a pearl eventually.

Global Evolution of Pearl Farming:

Ancient Pearl Gathering

- Wild pearl collection by divers.
- Found in rivers, seas & ocean.
- Practiced in China, India & Persian Gulf

Early Attempts at Farming (13th Century)

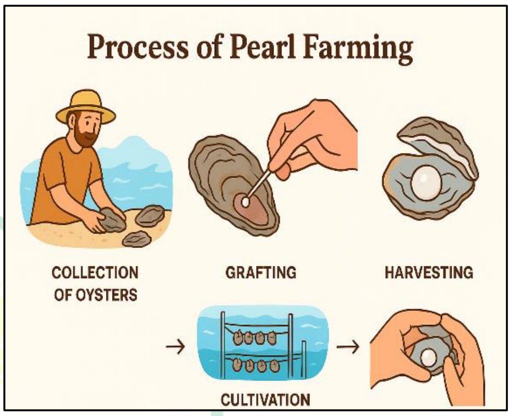
- China: First recorded pearl culture trials.
- Small objects were inserted into oysters.
- Similar efforts were made in Japan & India.

Technological Advancements (20th Century–Present)

- ✓ Improved breeding & nucleation techniques.
- ✓ Better oyster husbandry & water management.
- ✓ Increased yield & quality of pearls.

Steps in Pearl Farming:

a. **Collection of Oysters**: Gather young oysters from natural or hatchery sources.
b. **Nucleation (Seeding)**: Insert a small nucleus (bead) and mantle tissue into the oyster.
c. **Culture & Rearing**: Suspend oysters in cages or nets in the sea for 1–3 years.
d. **Monitoring & Care**: Clean shells regularly and protect from predators/diseases.
e. **Harvesting of Pearls**: Open the oysters carefully and collect matured pearls.
f. **Grading & Polishing**: Sort pearls by size, shape, luster, and polish for market.



Benefits of Pearl Farming:

Pearl farming offers several economic, environmental and social benefits, making it an attractive and sustainable aquaculture venture.

1. **High Market Value**
   The final product pearls is lightweight, durable and non-perishable, commanding a premium price in both domestic and international markets.
2. **Low Maintenance & Processing Cost**
   Processing pearls is simple, requiring no refrigeration or complex storage facilities. Hence, the overall cost of production is relatively lower compared to fish farming or other aquaculture systems.
3. **Integration with Other Aquaculture Activities**
   Pearl culture can be easily integrated with fish farming, prawn culture, or ornamental fish rearing, ensuring efficient use of water bodies and resources.
4. **Income Diversification for Farmers**
   It provides an additional source of income for rural farmers. Since freshwater mussels are commonly found in rivers, canals, and ponds, pearl farming can be conveniently practiced in village ecosystems.
5. **Environmental Sustainability**
   By promoting the cultivation of pearls in controlled conditions, the practice reduces pressure on natural oyster populations and contributes to biodiversity conservation.
6. **Employment Generation**
   Pearl farming creates employment opportunities for local youth and women through various activities such as seeding, maintenance, harvesting, and jewellery making.
7. **Eco-friendly Enterprise**
   Unlike many intensive farming practices, pearl culture does not require chemical fertilizers or feed, making it an environmentally friendly and sustainable livelihood option.

Pearl Farming: Profits and Cost Analysis

Parameter	Details
Oyster Price	₹20–30 per oyster
Pearl Price	₹300–1,500 per pearl (size 1–20 mm)
Market Demand	High demand in jewellery, cosmetics, paints, and clothing industries
Initial Investment	₹20,000–25,000 required to start a small-scale pearl farming unit
Potential Earnings	Up to ₹3,00,000 from a single production cycle
Return on Investment (ROI)	Approximately 50–60% of initial cost
Time to Profitability	Requires 2–5 years to achieve consistent income
Ease of Operation	Simple to manage, can be integrated with fish or prawn farming

Challenges in Pearl Farming in India

1. Very few freshwater pearl farmers in India.
2. Lack of organized sector and market linkages.
3. Poor broodstock management and scattered mussel availability.
4. Absence of standardized breeding and water quality protocols.
5. Limited research and development support.
6. Weak extension network for technology dissemination.

Government Initiatives for Pearl Farming

a. **Subsidies & Support:** Financial aid is provided under *Pradhan Mantri Matsya Sampada Yojana (PMMSY)* to reduce farming risk. Government offers subsidy upto 50 % of pond setup cost for pearl farming.

b. **Training & Technology Transfer:** ICAR–CIFA, Bhubaneswar conducts regular training for farmers and entrepreneurs.

c. **Skill Development:** Hands-on guidance is provided in implantation, mussel care, feeding and water quality management.

Pearl farming in India holds immense potential as a sustainable and profitable aquaculture enterprise. With proper training, organized sectoral support and adoption of scientific techniques, it can significantly enhance rural livelihoods and reduce dependence on traditional fisheries. Strengthening research, extension and government support will be key to unlock the full potential of this "blue treasure" industry.

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Microplastics: Emerging Pollutants in Aquatic Ecosystems

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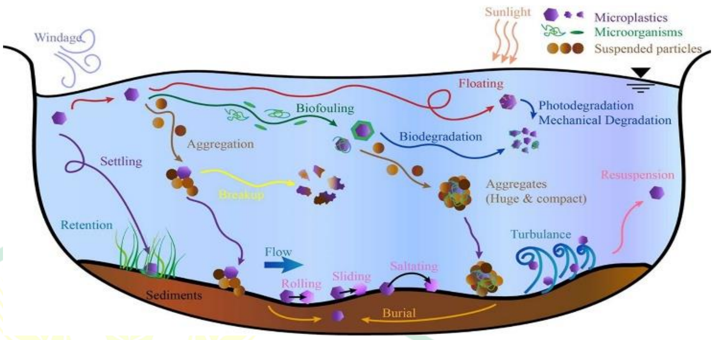
Introduction:

In every freshwater habitat, including buried lakes and flowing rivers, microplastics have been found. Inland aquatic environments are home to a wide variety of MPs. Microfibers make up the majority of it; it contains more than 80% of the pieces of plastic. Research on the source, path, and long-term impacts of MPs in freshwater ecosystems is ongoing. Sewage treatment plants and rainfall runoff are currently the main reasons of the lakes and rivers being affected. Recently, studies have been conducted to identify MP deposition in the freshwater ecosystem by airborne means (Shaun A. Forrest et al., 2020).



Microplastics in Freshwater Ecosystem:

Aquatic species contain MPs, which can lead to certain health problems. Additional research is required to understand the ramifications, which also include the build up of MPs in food systems (Xiong et al., 2023). Romera-Castillo et al. (2018) found that MPs have an impact on marine ecosystems and the marine environment because they emit dissolved organic carbon (DOC). The effects of ecological risk have become a crucial area of research, with many studies exploring how MPs affect both aquatic and terrestrial animals (Covernton et al., 2019). The routes MPs take in the lotic water system were identified, and their tendency to deposit in river bed sediments as a result of floods was noted. MPs can change in both physical and chemical ways, changing their size, structure, and properties. The research demonstrated that MPs have the ability to absorb organic contaminants and quickly deliver them to living things (Huang et al., 2021). Due to the long water residence period, accumulated MPs may persist for decades in lentic environments, which is of particular interest (Cera, A et al., 2022).Numerous external factors alter the occurrence and movement of MPsin lakes, including water flow and settling on the lakebed. These factors also affect the existence and dispersion of MPsin lakes. Geomorphic factors (water depth, coastline development), human activities (tourists, fishermen, dam releases), wind-induced surface currents, storms, floods, and runoff were among the sites they discussed where microplastics (MPs) are causing pollution. MP levels have been measured in samples taken from a number of lakes worldwide. The quantity and composition of MPs in Himalayan lakes, however, have not been extensively studied. Plastic particles (less than 5 mm) were discovered in the snow of Mount Everest, the world's tallest mountain (Napper et al., 2020).

Table 1. MPs distribution in lentic and lotic water bodies.

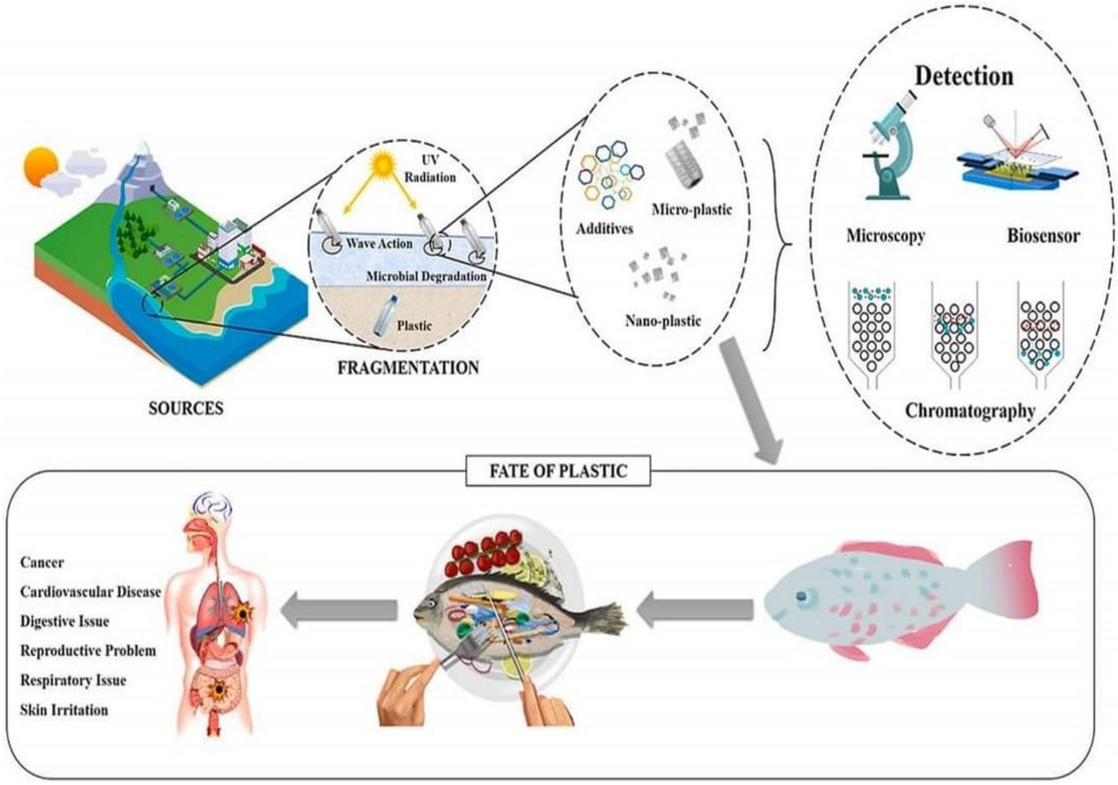
Fish species	Type of Polymers	Location	Concentration of MPs	References
European flounder and European smelt	PY, PP, PE	River Thames, U.K.	75%,20%	McGoran et al.,2017
Bluegill and longear	PY,PA,PE	Brazos river basin, U.S.A	45%	Khan M.L et al.,2023
Gudgeon	PY, PA, PE	Eleven French river	12%	Slootmaekers et al.,2019
Common goby	PE, Pyrene	Estuaries, Portugal.	Not identified	Oliveira et al.,2013
Gold fish	Microfibers	Canada, U.S.A	6%	Grigorakis et al.,2017
Zebra fish	PS	China	2%	Lu et al.,2022
Fathead minnow	PY, PC	Germany	0.0000158%	Greven et al.,2016

Microplastics in brackish water:

13% of coastal regions worldwide have estuaries, which act as a transitional area between landmasses and oceans (de Miranda et al., 2017). According to Lorenzi et al. (2021), the shallow coastal lagoons are crucial for the preservation of a number of ecosystem services, including habitat and reproduction for numerous species, water and fertiliser supply for agriculture, support for urban infrastructure, and recreational use. Therefore, it is seen to be effective to create marine conservation units (MCUs) around these places in order to protect and manage coastal lagoons (Dolbeth et al., 2016).Importantly, the scientific community has focused on plastics (particularly MPs) in aquatic environments due to their pervasiveness and possible ecological, social, and economic effects on flora and fauna (Lima et al., 2015). Every year, India generates over 5.6 million tonnes of plastic garbage. A Ramsar site was designated for the brackish water habitat known as Vembanad Lake. In addition to its global significance, it ensures the sustainable use and conservation of wetlands. Many contaminants, including heavy metals, are deposited in the lake by the seven major rivers as well as numerous streams and canals (Sruthy, S., & Ramasamy, E. V. 2017). MP is still likely to be present in the lake sediments because these rivers and streams pass through crowded urban areas. Because the locals work in agriculture, fishing, and other related fields, this lake is essential to their way of life. Numerous factors, including habitat loss, hydrodynamic changes, and low water quality, affect fish in the backwater as well. These factors may have an impact on ecological functions (Barletta et al., 2019) and prevent juvenile stages from reaching reproductive maturity (Ferreira et al., 2019). Because they consume microplastics during foraging, fish in estuaries are easily impacted by pollution under such conditions (Richard et al., 2018). The trophic transmission from the sick prey through direct eating causes greater vulnerability for predators at the top of the food chain (Au et al., 2017; Ferreira et al., 2016; Nelms et al., 2018). More and more studies are being conducted on fish consumption of microplastics (Bessa et al., 2018; McNeish et al., 2018; Silva et al., 2018). However, only recently, due to the discovery of contamination in economically important fish species, has attention been drawn to the relationship between species-specific ecological traits and microplastic intake (Ferreira et al., 2018).

Microplastics in finfish:

MPs are mistakenly consumed by pelagic and demersal fishes when searching the sediments for food, mistaking them for plankton or other food (Kibria.G,2023). According to Kibria et al. (2021a), filter feeders such as oysters and mussels also inadvertently consume MPs in addition to algae. Internationally, MPs have been discovered in the digestive tracts of numerous fish species (Rochman et al., 2015; Bellas et al., 2016; Su et al., 2019; Baalkhuyur et al., 2020). When plastic particles are coupled with fish, the ecological effects can include lower fertility, inflammation, pseudo satiation, and decreased organism-level fitness as a result of physical obstructions.But until recently, the gastrointestinal tract (GIT) often eliminates microplastics before they are consumed by humans, so they were not thought to pose a significant concern to food safety. MPs may carry organic pollutants, according to some scientific theories, which could release toxins into the shellfish's edible tissues. There is still disagreement in the scientific community on this issue (Barboza et al., 2018; Hantoro et al., 2019). Lab tests that show MPs transferring from the gastrointestinal system into other organs have nevertheless sparked concerns (Browne et al., 2008; Lu et al., 2016; Jovanović et al., 2018). In recent years, the topic has gained a lot of attention due to reports that MPs have been found in various fish tissues, such as the muscle, skin, and gills of fish that were taken in the wild from various nations (Akhbarizadeh et al., 2019). Since India is the second-largest producer of fish in the world and a major consumer and exporter of fish, it is essential to assess the amounts of microplastic



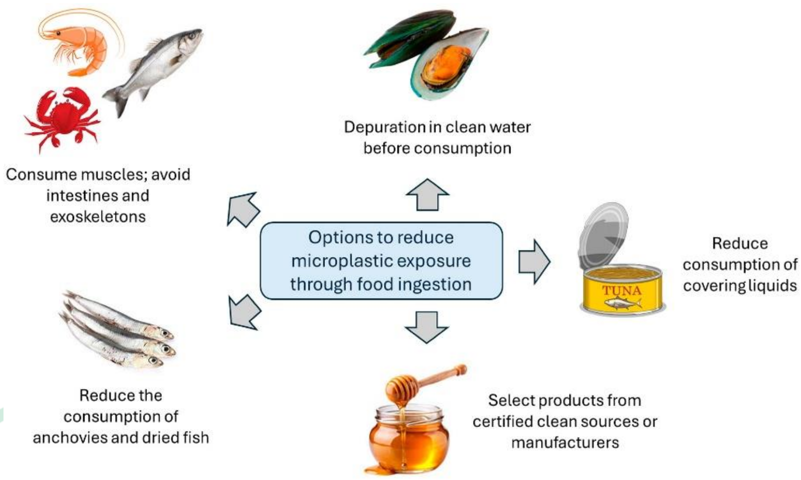
found in different fish species from the nation to guarantee the safety and quality of seafood.

Microplastics exposure in fishes and health risk asessment:

Several studies have found that mussels, crustaceans, and fish from freshwater and marine habitats carry small pieces of plastic in their digestive processes. These particles can move from the gastrointestinal tract to other parts of the body, including the hemolymph of mussels and crabs or organs like the liver (Avio 2016), brain (Ding et al., 2018), bloodstream, and fillet (Zeytin et al., 2020) of fish. This is especially true for particles in the lower micrometre to nanometre range. People may come into touch with plastic particles through marine products, especially when eating the full organism (such as mussels, oysters, or small fish like sprats).It can also accumulate in the human food chain and serve as a carrier for active substances like additives, component monomers, or contaminants found in the environment. Therefore, consumers may be at risk for health problems due to plastic particles in seafood (Barboza et al., 2020). According to a thorough investigation conducted by the European Food Safety Authority (EFSA), MPs, which range in size from 0.13 to 5 mm, are found in marine fish and shellfish. They so draw the conclusion that the exposure of microplastics in fish tissue has a substantial impact on the marine ecosystem as a result of human activities' inappropriate disposal of plastic. Several techniques are employed to identify and characterise MPs, such as pyrolysis gas chromatography-mass spectrometry (Py-GC-MS), infrared spectroscopy (IR), Raman spectroscopy, and electron microscopy (EM) (Schwarz et al., 2022).These methods include details on the size, shape, morphology, and chemical composition of MPs. According to Schwartz et al. (2022), they do have limitations in terms of quantification, notwithstanding the significant related costs. Velimirovic et al. (2021) have demonstrated that it is possible to identify, measure, and characterise the size of MPs in water samples using single particle inductively coupled plasma mass spectrometry (SP-ICP-MS). However, this technique had certain problems. Utilising materials with biological matrices requires a separate procedure for sample preparation. The MP content is determined by filtering the plastic particles out of the sample after the supernatant has been removed. Usually, a vacuum pump is utilised in conjunction with pore sizes that range from 0.3 to 200 µm.

Solutions to reduce the exposure to microplastics from finfishes:

The limitations on the production and use of microplastics align with the widespread initiatives to remove plastics from the oceans and the growing use of remediation technology to reduce plastic pollution in aquatic environments. To limit the release of microplastics, a number of regulatory measures are being implemented. As of 2017, the US had already banned the use of microplastic beads in cosmetics.The European Union (EU), Canada, Australia, and many other countries are also thinking about putting such effective safeguards into place. Microplastics are widely distributed, especially in aquatic environments, and their effects on marine organisms vary based on whether they release harmful chemicals from plastic additives or absorb pollutants like metals, pesticides, or persistent organic pollutants (Mihai et al., 2022).Microplastics can serve as reservoirs for the spread of infections, which means that if marine species harbour pathogens, consuming them could endanger human health, as shown by Goldstein and Goodwin (2013). Previous studies have shown that microplastic-containing environments have a negative impact on microorganisms (Li, Z et al., 2020). In addition to international initiatives to reduce plastic use and disposal, the ability to remove microplastics from industrial and municipal wastewater treatment systems is essential to reducing this risk.



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Liquid Organic Manures: Nature's Nutrient Boost for Sustainable Farming

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Intoduction

In recent years, farmers and gardeners alike are turning towards **organic farming practice** as an eco-friendly alternative to conventional farming with chemical fertilizers. One such practice gaining popularity is the use of **organic manures in nutrient management**. These are of solid (bulky) manures like FYM, compost, vermicompost and also some are in liquid formulations manures. In this aspect, liquid organic manures occupy a progressive space. They are not only cost-effective but also improve soil health, enhance nutrient availability and boost crop yields without harming the environment. With growing awareness about the ill effects of excessive chemical fertilizer use, farmers are increasingly looking for **eco-friendly and low-cost alternatives.** These natural formulations not only supply essential nutrients to crops but also rejuvenate the soil, stimulate plant growth and improve produce quality.

Key words: Liquid organic manures, jeevamrutha, panchagavya, soil drenching.

What are Liquid Organic Manures?

Liquid organic manures are **nutrient-rich plant tonics** prepared by fermenting animal wastes, crop residues or other organic materials in water. They supply essential macro and micro-nutrients to crops in an easily available form and also improve microbial activity in the soil.

Unlike bulky farmyard manure or compost, liquid manures act quickly because nutrients are present in soluble form. Farmers can apply them either to the soil or as a **foliar spray** directly on plant leaves. They also contain beneficial microbes, enzymes and growth-promoting substances, which improve nutrient uptake and enhance soil fertility over time.

What Makes Liquid Organic Manures Special?

Unlike bulky manures like compost or farmyard manure (FYM), organic liquid manures are **nutrient-rich solutions prepared by fermentation** of cow-based products, crop residues, fish waste or green plants.

- Nutrients are present in **readily available soluble form**, ensuring **quick response**.
- They contain **beneficial microbes, growth hormones, vitamins and enzymes**.
- They work both as:
    - **Fertilizers**: supplying N, P, K & micronutrients
    - **Biostimulants**: improving root growth, flowering and stress tolerance
    - **Bioprotectants**: offering resistance against pests and diseases

Advantages Over Chemical Fertilizers

1. **Low cost:** Prepared with farm wastes and locally available inputs.
2. **Safe for soil:** Improve microbial life instead of killing it.
3. **Balanced nutrition:** Provide both macro (N, P, K) and micro nutrients (Zn, Fe, Mn).
4. **Improves crop quality:** Better taste, aroma and keeping quality.
5. **Environmental safety:** Prevents groundwater contamination and reduces carbon footprint.
6. **Stress tolerance:** Helps crops withstand drought, salinity and pest attacks.

Popular Organic Liquid Manures

1. Jeevamrutha

- **Ingredients:** Cow dung (10 kg), cow urine (10 L), jaggery (2 kg), pulse flour (2 kg), handful of soil, and water (200 L).
- **Preparation:** Mix all ingredients in a drum, ferment for 5–7 days with daily stirring.

- **Use:** Apply 200 L per acre through irrigation water or as a foliar spray.
- Best suited for improving soil microbial activity and nutrient cycling.

2. **Panchagavya**
   - **Ingredients:** Five cow products (dung, urine, milk, curd, ghee) + banana, jaggery, coconut water.
   - **Preparation:** Ferment mixture in a plastic drum for 15–20 days, stirring twice daily.
   - **Specialty:** Improves flowering, fruit set and crop immunity.
   - **Use:** 3–5% foliar spray, repeat every 15 days.
3. **Amrit Pani**
   - **Ingredients:** Cow dung (10 kg), ghee (250 g), jaggery (1 kg), and water (200 L).
   - **Preparation:** Mix thoroughly and apply immediately.
   - **Use:** Soil application or seed treatment.
   - *Stimulates root growth and improves soil fertility.*
4. **Fish Amino Acid (FAA)**
   - **Ingredients:** Fish waste (1 kg), jaggery (1 kg).
   - **Preparation:** Keep mixture in airtight jar for 30–40 days for fermentation.
   - **Use:** Dilute (1:1000) and spray during vegetative growth.
   - **Specialty:** Nitrogen-rich—promotes leafy growth.
   - **Best for:** Spinach, coriander, cabbage, cauliflower.
   - *Rich in nitrogen, very effective for leafy vegetables.*
5. **Banana Pseudostem Extract**
   - **Ingredients:** Banana stem (5 kg), jaggery (1 kg).
   - **Preparation:** Chop stem, mix with jaggery, ferment for 7–10 days.
   - **Use:** Foliar spray (1:10 dilution).
   - *Excellent source of potassium, boosts flowering and fruit development.*
   - **Specialty:** Rich in potassium—enhances flowering and fruit size.
   - **Best for:** Banana, papaya, brinjal, tomato, chilli.
6. **Vermiwash**
   - **Preparation:** Collected as a drainage liquid from vermicompost units.
   - **Specialty:** Contains enzymes, hormones, vitamins and microbes.
   - **Use:** Dilute 1:5 and spray on leaves.
   - Contains vitamins, hormones, and enzymes that improve crop health.
7. **Leaf Extracts & Fermented Decoctions**
   - Extracts of neem, tulsi, custard apple, or Gliricidia leaves act as both **bio-fertilizers and natural pest repellents**.

Name	**Key Ingredients**	**Main Benefit**	**Best Use**
Jeevamrutha	Cow dung, cow urine, jaggery, pulse flour	Increases soil microbes & nutrient cycling	Soil application / irrigation
Panchagavya	Cow dung, urine, milk, curd, ghee, banana, coconut water	Enhances flowering, fruit set & immunity	Foliar spray (3–5%)
Amrit Pani	Cow dung, ghee, jaggery	Improves soil fertility & root vigor	Soil drenching
Fish Amino Acid	Fish waste + jaggery	Boosts leafy growth (rich in N)	Leafy vegetables
Banana Stem Extract	Banana pseudostem + jaggery	Rich in K – promotes fruit size	Banana, tomato, chilli
Vermiwash	Extract from vermicompost beds	Hormones & enzymes improve crop health	Foliar spray

Methods of Application

- **Foliar Spray:** Quickest effect, but must be diluted (1:10 or 1:20).
- **Soil Drenching:** Adds nutrients directly to the root zone.
- **Seed/Seedling Treatment:** Improves germination and early vigor.
- **Irrigation Mixing:** Easy method for large-scale application.

Do's and Don'ts for Effective Use

- Always ferment in **plastic drums or earthen pots**.
- Stir daily during fermentation.
- Apply in the morning or evening to avoid sun-scorch.
- Use **clean water** for dilution.
- Do not apply undiluted—it can burn plants.
- Avoid using expired or foul-smelling solutions.

Success Stories from Farmers

- **Vegetable growers in Andhra Pradesh** use Jeevamrutha twice a month, reporting **20–25% higher yield** and reduced fertilizer cost.
- **Banana farmers in Tamil Nadu** using banana stem extract achieved **better bunch size and fruit quality**.
- **Organic rice farmers in Karnataka** replace urea with liquid manures and maintain stable yields while saving input costs.

Recent Innovations

- **Commercial organic liquid formulations** like bio-digesters and microbial consortia are being sold, making them accessible to farmers who cannot prepare them.
- Mobile apps and FPOs are training farmers in **standardized preparation methods**.
- Research institutions are developing **fortified liquid manures** enriched with micronutrients like zinc and boron.

Crops That Respond Well

- **Vegetables:** Tomato, chilli, brinjal, okra, gourds, leafy greens.
- **Fruits:** Banana, papaya, guava, mango, citrus.
- **Field crops:** Paddy, maize, pulses, sesame, groundnut.
- **Plantations:** Coconut, arecanut, black pepper, cardamom.

Conclusion

Organic liquid manures are **farmers' friendly solutions** for nutrient management. They are inexpensive, easy to prepare and highly effective in boosting crop growth and quality. Liquid organic manures (LOMs) serve as an effective source of plant nutrients while promoting healthy growth and development. Notably, formulations such as panchagavya, vermiwash and fish amino acid are highly valued not only for their rich nutrient content but also for their role in pest repellence and disease management. These manures can be produced on a commercial scale by farmers and self-help groups. Future research priorities include scientific validation of LOMs with emphasis on shelf-life assessment, dosage standardization and identification of critical stages for application.

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Beyond Fertilizers: Biochar-Enriched Soils for Climate-Ready Farming

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Abstract

Farmers across the world are facing increasing climatic pressures including higher temperatures, prolonged dry periods and unpredictable rainfall. Conventional fertilizers can temporarily enhance yields, but they cannot rebuild degraded soil structure or improve the soil's capacity to retain water. Enriched biochar, which is biochar infused with nutrients, beneficial microorganisms or pH-adjusting minerals, presents a practical and sustainable strategy for developing climate-resilient soils while sequestering carbon for long-term storage (Lehmann and Joseph, 2015; Sun *et al*., 2022). This article explains what enriched biochar is, how it functions from the microscopic pore level to the field scale and the conditions under which it delivers the most benefits. It also summarizes evidence on yield improvement, water-use efficiency, nutrient cycling, soil biological health and carbon sequestration (Jeffery *et al*., 2011; Biederman and Harpole, 2013; Liu *et al*., 2021; IPCC, 2022).

The Problem Beneath Our Feet

Modern agriculture faces mounting challenges. Extended dry spells reduce the reach of root systems, while sudden heavy rains wash nutrients from the soil. Over time, the soil structure deteriorates, organic matter declines and microbial life weakens. Fertilizers can temporarily replenish nutrients, but they do not restore soil aggregation, improve water-holding capacity, or support microbial balance. Enriched biochar addresses these root-level problems. It is not merely a short-term nutrient addition but a stable carbon matrix that retains water, holds nutrients in place and offers habitat for beneficial microbes. For these reasons, enriched biochar is being recognized as a key component of climate-smart agriculture rather than an optional supplement (Lehmann and Joseph, 2015; Woolf *et al*., 2021).

What Enriched Biochar Means

Plain biochar is a carbon-rich, porous material produced through the controlled heating of biomass in limited oxygen. Enrichment involves charging this material with nutrients, microorganisms or minerals before field application. This can include soaking biochar in nutrient solutions containing nitrogen, phosphorus or potassium; inoculating it with beneficial microbes such as nitrogen fixers or phosphorus solubilizers; or mixing it with minerals that alleviate acidity or salinity (Sun *et al*., 2022; Liu *et al*., 2021).

The enrichment process transforms biochar from an inert structure into a biologically active, slow-release soil amendment. It acts like a sponge already filled with nutrients, releasing them gradually in alignment with plant needs. This reduces early nutrient losses, enhances root interaction and helps microbial communities establish faster (Agegnehu *et al*., 2017; Joseph *et al*., 2021).

Large-scale analyses consistently report improved crop yields and resource efficiency when biochar is used appropriately. The benefits are particularly evident in sandy, low-fertility or tropical soils. Enrichment further amplifies these effects by tailoring biochar composition to site-specific constraints (Jeffery *et al*., 2011; Biederman and Harpole, 2013; Liu *et al*., 2021; Sun *et al*., 2022).

How It Works: From Pores to Plots

1. Water Resilience

Biochar increases the porosity of soil across multiple scales. In coarse or degraded soils, this structural improvement enhances water infiltration and retention. Studies under water stress conditions show that biochar-treated crops maintain steadier photosynthesis and better leaf health, helping them endure dry periods (Liu *et al*., 2021; Abbas *et al*., 2022). When enriched biochar is combined with compost or organic water-holding materials, its effects on soil moisture are even stronger, especially in rainfed regions (Agegnehu *et al*., 2017).

2. Nutrient Efficiency

Nutrients stored within biochar are held on its surface and within its pores, minimizing leaching and releasing nutrients more gradually. Biochar-based slow-release fertilizers improve nutrient use efficiency and reduce nutrient runoff (Sun *et al*., 2022; Zhang *et al*., 2020). To maximize efficiency, enrichment should match the specific soil limitation. Phosphorus-enriched biochar works well in phosphorus-fixing tropical soils, while nitrogen-enriched biochar addresses early nitrogen deficiency in cereals (Agegnehu *et al*., 2017; Joseph *et al*., 2021).

3. Microbial Habitat and Soil Biology

Biochar provides a protected environment for beneficial microorganisms. It stabilizes pH and absorbs harmful compounds, creating favorable conditions for microbial growth. Research consistently shows that biochar applications promote more diverse and functional microbial communities, which enhance nutrient cycling and may suppress soil-borne diseases (Lehmann *et al*., 2011; Liu *et al*., 2021). Co-inoculating biochar with plant growth–promoting microorganisms further accelerates establishment and persistence (Joseph *et al*., 2021).

4. Carbon Removal and Climate Benefits

Biochar locks atmospheric carbon into a stable form that can remain in the soil for decades or centuries, making it a scientifically recognized carbon dioxide removal strategy (IPCC, 2022). On farms, biochar acts as a soil conditioner that simultaneously improves productivity and mitigates climate impact. With proper measurement and verification, biochar projects can also access carbon credits, helping farmers offset production and application costs (Woolf *et al*., 2021; IPCC, 2022).

Evidence from Research

Yield and Water-Use Efficiency

Across diverse soils, meta-analyses show that biochar consistently improves crop yields and water-use efficiency. The most significant effects occur in sandy, acidic or low-organic matter soils (Jeffery *et al*., 2011; Biederman and Harpole, 2013; Liu *et al*., 2021).

Soil Function and Health

Biochar enhances soil aggregation, increases cation exchange capacity, moderates soil pH, and improves water-holding capacity. These foundational changes strengthen resilience to both drought and heavy rainfall (Lehmann and Joseph, 2015; Abbas *et al*., 2022).

Engineered Biochar Solutions

Recent advances in engineered biochar, infused with nutrients or minerals, show promise in remediating saline or metal-contaminated soils. Such applications provide new opportunities for land restoration and sustainable intensification (Zhang *et al*., 2020; Sun *et al*., 2022).

Circular Economy and Cost Efficiency

Using locally available crop residues as feedstock minimizes transport expenses and keeps nutrient cycles localized. In areas where carbon markets are accessible, biochar adoption can yield additional financial returns (Woolf *et al*., 2021; IPCC, 2022).

Practical Applications: When and Where It Works Best

Ideal Scenarios

- Degraded or sandy soils requiring improved structure and water retention (Liu *et al*., 2021).
- Low-fertility or tropical soils where nutrient retention and pH buffering provide substantial yield gains (Jeffery *et al*., 2011; Biederman and Harpole, 2013).
- Rainfed systems prone to erratic monsoons or periodic droughts where efficient water use is essential (Abbas *et al*., 2022; Liu *et al*., 2021).

Best Practices

- Match enrichment to soil limitations: use phosphorus-enriched biochar in phosphorus-fixing soils, nitrogen-enriched biochar for early nitrogen needs, and calcium or magnesium-enriched biochar in acidic soils (Agegnehu *et al*., 2017; Sun *et al*., 2022).
- Blend biochar with compost or manure to stimulate microbial activity and prevent temporary nitrogen deficiency in poor soils (Agegnehu *et al*., 2017).

- Combine biochar with moisture-retention strategies such as mulching in drought-prone zones (Abbas *et al*., 2022).

Application and Rates

Application rates vary widely depending on soil type and purpose. Many successful cases use gradual incorporation into the root zone. Banding biochar along crop rows, charging it with nutrient solutions before application, and piloting small test plots before scaling up are effective strategies (Lehmann and Joseph, 2015; Liu *et al*., 2021).

Common Pitfalls and How to Avoid Them

Assuming Uniform Results

Biochar performance depends on several factors such as feedstock, pyrolysis temperature, soil texture, climate, and crop species. Conducting small field trials before large-scale use is essential (Lehmann and Joseph, 2015).

Nutrient Imbalance

Unenriched biochar can temporarily immobilize nitrogen in very poor soils. Pre-charging biochar with nutrients or applying it along with organic matter can prevent early nitrogen deficiency (Agegnehu *et al*., 2017; Sun *et al*., 2022).

Quality Control

Always verify the quality of biochar before use. Check its pH, electrical conductivity, ash content and potential contaminants such as heavy metals or polycyclic aromatic hydrocarbons, especially when derived from mixed waste materials (Lehmann and Joseph, 2015; Zhang *et al*., 2020).

Economic Viability

Transportation and handling costs can limit adoption. Using local feedstocks, establishing decentralized production units and engaging with carbon offset programs can enhance profitability (Woolf *et al*., 2021; IPCC, 2022).

The Climate-Ready Advantage

Soil is the foundation of every farming system. Enriched biochar acts as a long-lasting filter that keeps this foundation strong, ensuring that each drop of rainfall is used efficiently and that nutrients remain accessible to plant roots. At the same time, it sequesters carbon, helping to combat climate change. As environmental pressures intensify, enriched biochar represents a scientifically proven, practical and scalable approach to sustainable agriculture. Starting with small, targeted trials and scaling up gradually allows farmers to tailor applications to their specific soil and climatic needs, building more resilient soils for the future (Lehmann and Joseph, 2015; Sun *et al*., 2022; IPCC, 2022).

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e-NAM 2.0: Expanding India's Digital Agri-Market to 247 Commodities A Leap Toward One Nation, One Market, One Future

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Abstract

The National Agriculture Market (e-NAM), India's pioneering digital agri-trade platform, continues to redefine agricultural marketing by integrating technology, transparency and inclusivity. Launched in 2016 to unify the nation's fragmented mandi system, e-NAM now connects over 1,500 markets across 23 states and 4 union territories. In October 2025, the Department of Agriculture and Farmers Welfare (DA&FW) announced the inclusion of nine new commodities—taking the total to 247. This strategic expansion reflects India's growing commitment to digital transformation in agriculture, offering farmers better market access, quality-linked pricing and greater economic empowerment. This article explores e-NAM's evolution, technological architecture, benefits and the significance of its latest expansion.

Introduction: Digitizing the Agricultural Marketplace

Agriculture remains the backbone of India's economy, employing nearly half of the workforce and contributing significantly to rural livelihoods. However, traditional agricultural marketing systems dominated by localized Agricultural Produce Market Committees (APMCs) have posed challenges of **price disparity, limited market access** and **dependence on intermediaries**.

In response, the Government of India launched the **National Agriculture Market (e-NAM)** on **14 April 2016**, under the **Digital India initiative**, as a revolutionary step toward market unification. The platform seeks to integrate APMC mandis nationwide into a single, transparent and technology-driven marketplace.

The vision was clear: to empower farmers with **real-time price information, digital trading facilities and fair competition,** ensuring they earn remunerative prices for their produce.

Evolution of e-NAM: From Vision to Reality

When e-NAM was first introduced, it connected only **585 mandis across 8 states**. Within less than a decade, it has expanded to **1,522 mandis across 23 states and 4 Union Territories**, transforming India's agri-marketing landscape.

The initiative is **funded by the Central Government and implemented by the Small Farmers Agribusiness Consortium (SFAC)** under the **Ministry of Agriculture and Farmers Welfare.** SFAC plays a central role in coordinating with state governments, developing the e-trading infrastructure and providing training to farmers and traders.

States such as **Tamil Nadu (213 mandis), Rajasthan (173)** and **Gujarat (144)** have emerged as leaders in integrating local mandis into the e-NAM network, setting examples for others to follow.

This vast digital infrastructure has turned what was once a **fragmented mandi ecosystem** into a **nationwide, unified marketplace**, empowering both small and large farmers alike.

Objectives of e-NAM

The e-NAM platform was designed with the following objectives:

- **Integration of Mandis:** Unify state APMC markets into a national electronic platform.
- **Transparent Price Discovery:** Facilitate real-time, competitive bidding to determine fair prices.
- **Digital Transactions:** Ensure seamless and secure payments directly to farmers' bank accounts.
- **Reduction in Intermediaries:** Minimize middlemen and enhance farmers' share in consumer prices.
- **Quality Standardization:** Introduce tradable parameters to link prices with quality.
- **Market Expansion:** Enable inter-state trading and access to a wider base of buyers.

By achieving these objectives, e-NAM aligns closely with the government's vision of **"Atmanirbhar Krishi"** (self-reliant agriculture).

The Technological Framework: How e-NAM Works

The strength of e-NAM lies in its robust **digital architecture,** which integrates farmers, traders, commission agents and buyers on a single virtual platform.

Key Features of e-NAM:

- **Online Trading & Bidding:** Farmers and traders can participate in transparent e-auctions.
- **Real-Time Price Discovery:** Prices are determined through demand-supply dynamics.
- **Quality Testing & Grading:** Ensures uniformity and trust between buyers and sellers.
- **Digital Payments:** Enables direct transfer of sale proceeds to farmers' accounts.
- **Data Analytics:** Provides insights into market trends, arrivals and commodity demand.
- **Mobile App:** Available in 13 Indian languages, allowing farmers easy access to trading and market data.

This comprehensive integration of technology has not only modernized trading but also reduced manual processes, making transactions faster and more efficient.

The 2025 Expansion: 9 New Commodities Added

In October 2025, the Department of Agriculture and Farmers Welfare announced a major expansion of the e-NAM platform with the inclusion of **nine new commodities**, increasing the total from 238 to **247 tradable items.** The newly added commodities are:

1. Green Tea
2. Tea
3. Aswagandha Dry Roots
4. Mustard Oil
5. Lavender Oil
6. Mentha Oil
7. Virgin Olive Oil
8. Lavender Dried Flower
9. Broken Rice

Significance of the New Additions

This expansion reflects a strategic effort to diversify India's agri-trade portfolio, incorporating **high-value crops, medicinal plants and essential oils**—sectors with immense domestic and export potential.

Products like **Aswagandha** and **Lavender Oil** cater to the **wellness and pharmaceutical markets**, while **Mustard Oil** and **Virgin Olive Oil** strengthen India's edible oil trade. The inclusion of **Broken Rice** enhances the value chain for processed grains, vital for food security and export growth.

This diversification signals e-NAM's shift from a focus on traditional cereals to a more **value-driven and export-oriented agriculture.**

Role of the Directorate of Marketing and Inspection (DMI)

The **Directorate of Marketing and Inspection (DMI)** plays a crucial role in developing **tradable parameters—** quality and grading standards for commodities traded on e-NAM.

These parameters ensure that each product is evaluated on a **uniform scale**, linking its price directly to its quality.

DMI formulates these standards in close coordination with **state agricultural marketing boards, traders, subject experts and SFAC** and every new inclusion is approved by the **Union Minister of Agriculture and Farmers Welfare.**

As of 2025, DMI has formulated tradable parameters for **247 commodities**, fostering **transparency, quality assurance and trust** in India's agri-markets.

By promoting quality-linked pricing, DMI's work empowers farmers to produce better and helps them receive **price premiums for superior-grade produce.**

e-NAM's Integration with the Platform of Platforms (PoP)

In July 2022, e-NAM was integrated with the **Platform of Platforms (PoP)**, a significant milestone that expanded its functionality beyond trading.

The PoP connects e-NAM users with a range of **public and private agri-service providers**, creating a **comprehensive digital ecosystem** for agriculture.

Through this integration, farmers and traders can now access:

- **Transport and logistics services** for efficient movement of produce.
- **Warehousing and cold storage facilities** to minimize post-harvest losses.
- **Testing and certification labs** for ensuring quality compliance.
- **Input suppliers** for seeds, fertilizers and agri-equipment.
- **Financial and insurance services** for risk mitigation.

The PoP marks a new era where farmers can manage the **entire value chain digitally**, from production to marketing, all on a single platform.

Benefits of e-NAM for Farmers

a. Transparent Pricing: Farmers can view real-time prices across markets, ensuring competitive and fair trade.

b. Direct Payments: Digital transactions reduce cash handling and eliminate delays.

c. Broader Market Reach: Farmers can now sell to buyers in different states, gaining national visibility.

d. Quality-Based Rewards: Standardized grading ensures that better-quality produce earns better prices.

e. Empowering FPOs: Farmer Producer Organizations (FPOs) aggregate produce, improving small farmers' bargaining power.

Through these benefits, e-NAM is reshaping rural economies by ensuring that farmers are not merely producers but informed market participants.

State-Level Achievements: Tamil Nadu Leading the Way

Among the top-performing states in e-NAM integration, **Tamil Nadu leads with 213 mandis.** The state's proactive approach in digitizing its agricultural markets has resulted in:

- Faster online transactions.
- Greater participation from smallholder farmers.
- Increased transparency in price discovery.

Rajasthan and Gujarat follow closely, demonstrating how regional collaboration and strong institutional support can accelerate the digital transformation of agricultural marketing.

Challenges and the Road Ahead

Despite remarkable progress, several challenges remain:

- **Digital literacy gaps** among small and marginal farmers.
- **Limited internet connectivity** in remote rural areas.
- **Resistance from traditional intermediaries** in some regions.
- **Need for uniform quality testing infrastructure** across mandis.

To address these, the government is investing in **rural broadband expansion**, **digital training programs** and the integration of **AI-based grading and data analytics** to enhance decision-making and forecasting in agricultural trade.

Future initiatives also aim to integrate **export facilitation**, **blockchain traceability** and **AI-driven price prediction** to align Indian agriculture with global market standards.

e-NAM updates (As of October 2025)

Parameter	Details
Launch Date	14 April 2016
Implementing Agency	SFAC, Ministry of Agriculture & Farmers Welfare
Mandis Integrated	1,522 in 23 States & 4 UTs
Total Commodities Traded	247
Languages Supported	13
Mobile App & PoP Launch	14 July 2022
Top State	Tamil Nadu (213 mandis)
Smallest Participants	Chandigarh (1) andaman & Nicobar (1), Puducherry (2)

Global Perspective: India as a Digital Agriculture Pioneer

India's success with e-NAM is increasingly viewed as a **model for developing nations** striving to digitize their agricultural marketing systems.

The platform demonstrates how **policy reform, public-private collaboration** and **digital innovation** can transform agriculture into a more inclusive and efficient sector.

As countries in Africa, Southeast Asia and Latin America explore similar models, e-NAM stands as a testament to India's leadership in **agri-digital governance**.

Conclusion

The expansion of e-NAM to **247 commodities** marks a significant milestone in India's agricultural modernization journey. It reflects the government's sustained commitment to building a transparent, inclusive and technology-driven marketplace that empowers farmers at every level.

By linking price with quality, reducing dependence on intermediaries and facilitating direct access to markets, e-NAM is redefining agricultural trade in India.

As the platform evolves with new technologies and services, it holds the promise of realizing **"One Nation, One Market"** in its truest sense—ensuring that every farmer, regardless of scale or location, can trade confidently, transparently and profitably.

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Brackish Water Irrigation in Arid and Semi-Arid Regions: Impacts, Management, and Sustainable Practices India's Golden Grain and Hidden Health Risk

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Abstract

Brackish water, characterized by moderate dissolved salts, is an increasingly important irrigation resource in arid and semi-arid regions facing freshwater scarcity. Its use influences soil properties, crop growth, and yield due to salinity, sodicity, and ion toxicity. Key quality indicators such as electrical conductivity (EC), sodium adsorption ratio (SAR), and residual sodium carbonate (RSC) determine suitability for irrigation. Management strategies, including blending with freshwater, leaching, gypsum and organic amendments, crop selection, and optimized irrigation, can mitigate adverse effects. Sustainable utilization of brackish water ensures agricultural productivity while preserving soil fertility and environmental health.

***Keywords**: Brackish water, irrigation, soil salinity, sodium adsorption ratio, water management, soil fertility, salinity mitigation, sustainable agriculture*

Introduction

Water is the most critical resource supporting agriculture, industry, and domestic needs. In arid and semi-arid regions, freshwater availability is limited due to population growth, urbanization, and climate variability (Singh et al., 2020). Brackish water, containing total dissolved salts (TDS) of 1,000–10,000 mg L^{-1} or an EC of 1.5–10 dS m^{-1}, has emerged as a vital alternative irrigation source (Ayers & Westcot, 1985; Rhoades et al., 1992).

In India, groundwater in states like Haryana, Rajasthan, Gujarat, and Tamil Nadu often exhibits brackish characteristics due to high evaporation, poor drainage, and mineral weathering (Minhas & Gupta, 1992). Improper use of brackish water can lead to soil salinization, reduced crop yield, and degradation of soil structure (Qadir & Oster, 2004).

Brackish water contains elevated concentrations of sodium (Na^+), chloride (Cl^-), sulphate (SO_4^{2-}), and bicarbonate (HCO_3^-) ions, affecting the soil water plant continuum (Minhas, 1996). High SAR and RSC levels deteriorate soil permeability, reduce infiltration, and disturb nutrient balance (Gupta & Abrol, 1990). Judicious management such as leaching, blending with freshwater, gypsum application, and crop selection ensures sustainable crop production (Minhas et al., 2007).

Brackish Water Characteristics and Quality Parameters

1. Physical Properties

- Electrical Conductivity (EC): Indicates total salt load; EC > 3 dS m^{-1} is often considered marginally suitable for sensitive crops.
- Total Dissolved Solids (TDS): Reflects dissolved salts in mg L^{-1}.
- pH: Slightly alkaline water (≈6.5–8.5) is common in brackish sources.

2. Chemical Properties

- Cations: Sodium (Na^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+)
- Anions: Chloride (Cl^-), Sulfate (SO_4^{2-}), Bicarbonate (HCO_3^-), Carbonate (CO_3^{2-})

3. Derived Indices

- Sodium Adsorption Ratio (SAR): Risk of sodium-induced soil dispersion.
- Residual Sodium Carbonate (RSC): Excess bicarbonate/carbonate relative to $Ca^{2+} + Mg^{2+}$, causing alkalinity.
- Other indices: Kelly's Ratio (KR), Permeability Index (PI), %Na, Magnesium Hazard (MH).

Table 1: Classification of Brackish Water Based on EC, SAR, and RSC

Water Class	EC (dS m⁻¹)	SAR	RSC (meq/L)	Suitability
Good	<3	<10	<1	Safe
Marginal	3–6	10–18	1–2	Crop-specific
Unsuitable	>6	>18	>2	Not recommended

Impact of Brackish Water on Crops

1. Soil and Root Environment: Saline irrigation increases soil salinity and sodicity, reducing osmotic potential and hindering water uptake. High Na^+ replaces Ca^{2+} and Mg^{2+}, causing dispersion, crust formation, and reduced infiltration (Sharma et al., 2022).
2. Crop Germination and Growth: Salinity stress delays seed germination and reduce seedling vigour. Sensitive crops like black gram, chickpea, onion, and tomato are particularly affected (Patel et al., 2021).
3. Yield and Crop Quality: Excess Na^+ and Cl^- impair metabolic processes, photosynthesis, and enzyme activity, reducing yield and quality (Minhas et al., 2023).
4. Differential Crop Response: Crops such as barley, cotton, mustard, sorghum, and date palm are more tolerant, while rice, onion, and mung bean are sensitive (Kumar et al., 2023).
5. Long-Term Implications: Continuous use of brackish water without management reduces soil fertility, microbial activity, and long-term productivity (Kumar & Sharma, 2024).

Management Strategies

1. Blending and Conjunctive Use: Mixing brackish water with freshwater reduces EC and SAR. Alternating fresh and saline irrigation maintains salt balance in the root zone (Singh et al., 2022).
2. Leaching and Drainage: Periodic leaching below the root zone prevents salt accumulation. Proper drainage, ridge-furrow systems, and raised beds enhance crop establishment (Sharma et al., 2021).
3. Soil Amendments: Gypsum replaces exchangeable Na^+ with Ca^{2+}, improving soil structure. Organic amendments like compost and green manure buffer soil and enhance nutrient availability (Kumar et al., 2023).
4. Crop and Variety Selection: Salt-tolerant crops such as barley, mustard, cotton, and sorghum can withstand higher salinity. Breeding and biotechnological interventions improve tolerance (Meena & Singh, 2020).
5. Irrigation Scheduling and Fertility: Frequent, light irrigation dilutes salts. Split application of N and foliar nutrition (K, B, Zn) mitigates salt stress (Qureshi et al., 2022).
6. Mulching and Bio-amelioration: Surface mulches reduce evaporation and upward salt movement. Halophytes like *Leptochloa fusca* can reclaim saline soils (Yadav et al., 2023).

Field Studies from India

Haryana and Rajasthan: These states have pioneered brackish water use through conjunctive irrigation. Studies at the Central Soil Salinity Research Institute (CSSRI), Karnal, revealed that wheat and mustard could be successfully grown using groundwater of EC up to 4 dS m^{-1} when managed with gypsum and periodic leaching (Minhas & Gupta, 1992).

Gujarat and Coastal Regions: In coastal Gujarat, farmers use saline groundwater mixed with canal water for cotton and sorghum. Adoption of ridge–furrow planting and drip systems has minimized salt accumulation and maintained yields (Gupta et al., 2010).

South India: In Tamil Nadu, saline aquifers with EC between 2–5 dS m^{-1} are used for rice and groundnut with green manure incorporation and alternate wetting and drying irrigation, showing improved productivity and soil health (Kumar & Yadav, 2019).

Conclusion

Brackish water is a critical alternative in water-scarce regions, but its moderate salinity and high Na^+, Cl^-, and HCO_3^- levels can adversely affect soil and crop productivity. Without management, long-term use may cause salinization, nutrient imbalance, and yield decline. Integrated strategies—including blending with freshwater, gypsum and organic amendments, salt-tolerant crops, irrigation scheduling, and leaching—can mitigate negative effects. Sustainable use ensures productive agriculture while preserving soil fertility and environmental health, making brackish water a viable resource for arid and semi-arid regions.

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Reviving ancient traditions of farming for a greener and sustainable future

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Abstract

The revival of ancient agricultural traditions offers a potential pathway toward sustainable and resilient farming systems in response to modern environmental crises such as soil degradation, water scarcity and biodiversity loss. This paper explores Vedic and traditional Indian farming practices including Vedic agriculture, Homa (Agnihotra) farming, biodynamic and organic systems that emphasize harmony with natural cycles, organic soil enrichment and ecological balance. Empirical evidence indicates that traditional inputs like Panchagavya, Jeevamrutha and Agnihotra ash enhance soil fertility, nutrient content and crop resilience. Studies further demonstrate improvements in soil structure, mineralizable nitrogen and economic returns under integrated traditional-organic regimes. While organic and biodynamic systems can significantly boost productivity in developing regions, their yield potential remains crop and location-specific. The integration of ancient wisdom with modern scientific approaches presents a viable, ecologically sound model for ensuring long-term agricultural sustainability and food security.

Introduction

When tragedy strikes, humanity instinctively searches for solutions, often by revisiting the roots of our existence. The growing environmental crises, soil degradation, water scarcity and climate change have driven many to question the sustainability of modern agriculture. Shall we go back to the ancient agriculture is not merely a nostalgic thought, it is an inquiry into whether traditional farming methods with their harmony with nature, resilience to stress and minimal reliance on synthetic inputs, could offer answers to today's agricultural challenges. This exploration considers how ancient wisdom might merge with modern science to create a sustainable path forward.

Human life is dependent on 'Anna' and production of Anna is dependent of agriculture. Vedic seer says; 'O gambler, stop gambling and engage yourself in agriculture, which is regarded as most valuable wealth, so that you will earn wealth, happiness, cattle and happy married life'. You respect this wealth and be content with this wealth.

We are still relying upon the ancestral methodology in the current scenario. Till today, some farmers can say when will be the rainfall occur by observing some changes in surroundings. Till today, we believe in the movement of nakshatras, sun and moon and practicing the agriculture. Like this many facts are practiced by us but still we are running behind the mirage of development.

Problems associated with conventional agriculture

1. **Soil degradation:** Continuous mono cropping and excessive chemical inputs lead to reduced soil fertility, loss of organic matter, poor structure, low water-holding capacity and increased salinity or sodicity.
2. **Water resource stress:** Overexploitation of surface and groundwater for irrigation causes depletion, disrupts natural hydrological cycles and exacerbates water scarcity.

3. **Agrochemical pollution:** Persistent pesticide residues and nutrient runoff contaminate groundwater and surface waters, contributing to eutrophication, harmful algal blooms and aquatic ecosystem decline.
4. **Biodiversity loss:** Genetic uniformity in crops and livestock reduces resilience to pests, diseases and climate stress, while overgrazing accelerates desertification in fragile ecosystems.
5. **Pest and pathogen resistance:** Intensive pesticide use has led to widespread resistance among insects, mites and fungal pathogens, undermining long-term pest management effectiveness.

Vedic agriculture

Vedic agriculture in ancient India integrated advances in science and mathematics to improve farming practices, emphasizing ploughing, sowing and harvesting during favorable periods based on astronomical observations. Farmers recognized the importance of natural cycles, using knowledge of the weather and monsoons to optimize crop production. The main crops included wheat, barley and various nuts and cultivation relied on solar energy for optimal growth. Vedic farmers also introduced organic manuring, recycling materials like leaves and cow dung to enhance soil fertility. Ancient texts such as the Atharvaveda provided guidance on maintaining soil health and productivity through scientific and sustainable methods.

Homa-farming (Agnihotra)

It is a spiritual agricultural practice from the Vedic period, involving the chanting of specific Sanskrit mantras at precise times before a sacred fire to purify and energize the environment. It does not involve direct farming methods but claims to enhance the vitality of the farm and household where performed. The ash produced from Agnihotra rituals is applied to compost, soil and plants, purportedly improving their energy and growth, with the process being accessible, cost-effective and reliant on regular discipline.

Biodynamic farming

Biodynamic farming focuses on increasing the nutritional quality and vitality of food while restoring and maintaining the health of soil, seeds and water through organic matter enhancement. It encourages farmers to form a close, cooperative relationship with nature, aiming to regenerate resources and support ecological balance. The main goal is to sustainably serve the earth and its ecosystems, especially by revitalizing areas degraded by intensive use.

Organic farming

Organic farming, also known as eco-farming or biological agriculture, emphasizes cultivation without synthetic fertilizers or pesticides and relies on natural inputs and processes. In India, about 11.8 million acres are under organic certification, mostly for forest collections, with only 1.8 million acres used for certified crop cultivation. The annual organic production is approximately 1.24 million tons with 15 per cent exported. Common misconceptions include beliefs that organic yields are always lower than conventional farming, that it is not economically viable and that compost alone cannot meet crop nutrient requirements. Additionally, some wrongly assume organic farming is defined only by the non-use of chemicals or that it guarantees high profits.



Some assisted and unassisted statements

- Organic farming may increase yields in regions where industrialized agriculture is not prevalent (Barbieri).
- If all farming was organic, the world could only produce enough food for 5.9 billion people, compared to 7.9 billion by conventional systems, indicating that organic agriculture alone might not meet global food demand (Barbieri).
- Traditional farming techniques can improve and conserve soil health and fertility (Leinweber et al., 2019).
- Ancient soil management practices in organic farming offer sustainable ways to maintain food production, and these methods can help mitigate climate change by enhancing the soil's capacity to store greenhouse gases (Leinweber et al., 2019).

- Organic agriculture can substantially boost productivity in developing countries, potentially feeding the global population (Bedgley et al., 2007).
- Some experts state that organic farming alone cannot provide enough food for the world's population (D.J. Connor, 2007).

Literature reviews

1. Homa organic farming and related Vedic techniques, using inputs such as cow urine, dung and Agnihotra homa ash, improved yields and soil nutrient status in tomato and soybean, as demonstrated by Brunda et al. (2011) and Namrata et al. (2009).
2. Liquid manures like Jeevamrutha, Beejamrutha, Panchagavya and compost teas significantly enhanced yields in vegetables (knol-khol, onion, pea, french bean, paddy) and improved nutrient content and disease resistance, according to Sanjay Chadha et al. (2012).
3. The use of vermiwash, panchagavya and related organic amendments was effective against major soil-borne pathogens, confirming the benefits for plant health and resilience (Sanjay Chadha et al., 2012).
4. Biodynamic approaches led to improved soil structure, lower bulk density, and greater mineralizable nitrogen than conventional methods, as shown by Vereijken (1986), Reganold and Palmer (1994) and Kratz & Schnug (2007).
5. In long-term field trials, net returns and benefit-cost ratios were higher or comparable under integrated traditional-organic management for major cropping systems (Somasundaram et al., 2001-03; Ram & Pathak, 2007).
6. Significant yield and seed quality improvements for crops such as soybean were seen under organic and biodynamic regimes, with evidence from studies by Lam Dong Tung & Fernandez (2005) and D.K. Singh et al. (2013-15), although not all crops or regions show equal benefit.

Conclusion

A shift towards ancient agricultural methods can enhance soil health, ecosystem resilience and self-reliance, while reducing input costs and supporting sustainable practices, especially for vegetables and pulses. However, yield outcomes are highly location specific and may not match those of intensive commercial systems for all crops. Integrating proven ancestral techniques with modern innovations offers a balanced, scientific approach to address declining farmland and farmer numbers, while sustaining productivity and environmental integrity.

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NATURE'S BIOINDICATOR BRIGADE: INSECTS AS ENVIRONMENTAL MONITORS

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INTRODUCTION

Every organism on the earth tells a story about their surroundings, insects play major role among them, they act as living sensors. Insects form the largest and most diverse group of organisms on Earth, occupying almost every habitat from mountain streams to desert sands. Beyond their familiar roles as pollinators, decomposers, and predators, insects also serve as early warning signals of environmental change. The life cycles of insects are fast; they are influenced by environmental variations hence they function as precursors of environmental disturbance, indicating ecosystem changes earlier than other organisms. As insects useful in the evaluation of environmental health they are considered as "bio-indicators". Bioindicators are any species or group of organisms which represents the biotic or abiotic condition of the ecosystem. It shows how environmental changes affect a habitat or ecosystems, revealing whether the impact is beneficial or harmful. They provide a novel method to detect environmental mismanagement, including pollution, soil degrading intensive farming, contamination and incorrect waste disposal. This article explores how different insect groups act as natural bioindicators.

RATIONALE FOR USING INSECTS AS BIOINDICATORS

1) Highly sensitivity to environmental changes:

Insects are highly sensitive to environmental changes such as pollution, temperature, humidity which affects their survival, abundance and behaviour.

2) Wide distribution and diversity:

Insects occupy almost each and every habitat (soil, water, air, forest and agriculture ecosystem). Their wide distribution makes them suitable for indicating environmental conditions.

3) Shorter life cycle:

Insects reproduce quickly and have short life spans, so they show the effects of pollution or habitat disturbance much faster.

4) Specific habitat requirements:

Certain insect species can thrive only in clean or unpolluted environment (Example: Mayflies, stoneflies in freshwater). Monitoring the presence or absence of the particular species indicates the health of the habitat.

5) Easy sampling and identification:

Insects can be easily collected and identified making then practically applicable for field monitoring and ecosystem studies.

6) Ecological relevance:

Changes in insect communities directly affect food webs, plant reproduction and decomposition process- making their monitoring ecologically meaningful.

INSECT GROUP AS INDICATORS OF BIODIVERSITY:

Different insect groups respond uniquely to habitat quality, pollution and climate variations making then valuable monitoring ecological integrity.

1. Ephemeroptera: Mayflies that inhabit freshwater ecosystem are considered excellent bioindicators. Their larvae spend their entire cycle in water and more sensitive to dissolved oxygen in water. They thrive only in well-aerated unpolluted water, highly sensitive to organic and chemical contaminants, heavy metals, acidic water. Decrease in the mayfly population indicates the water pollution.

Mayfly naiad and adult

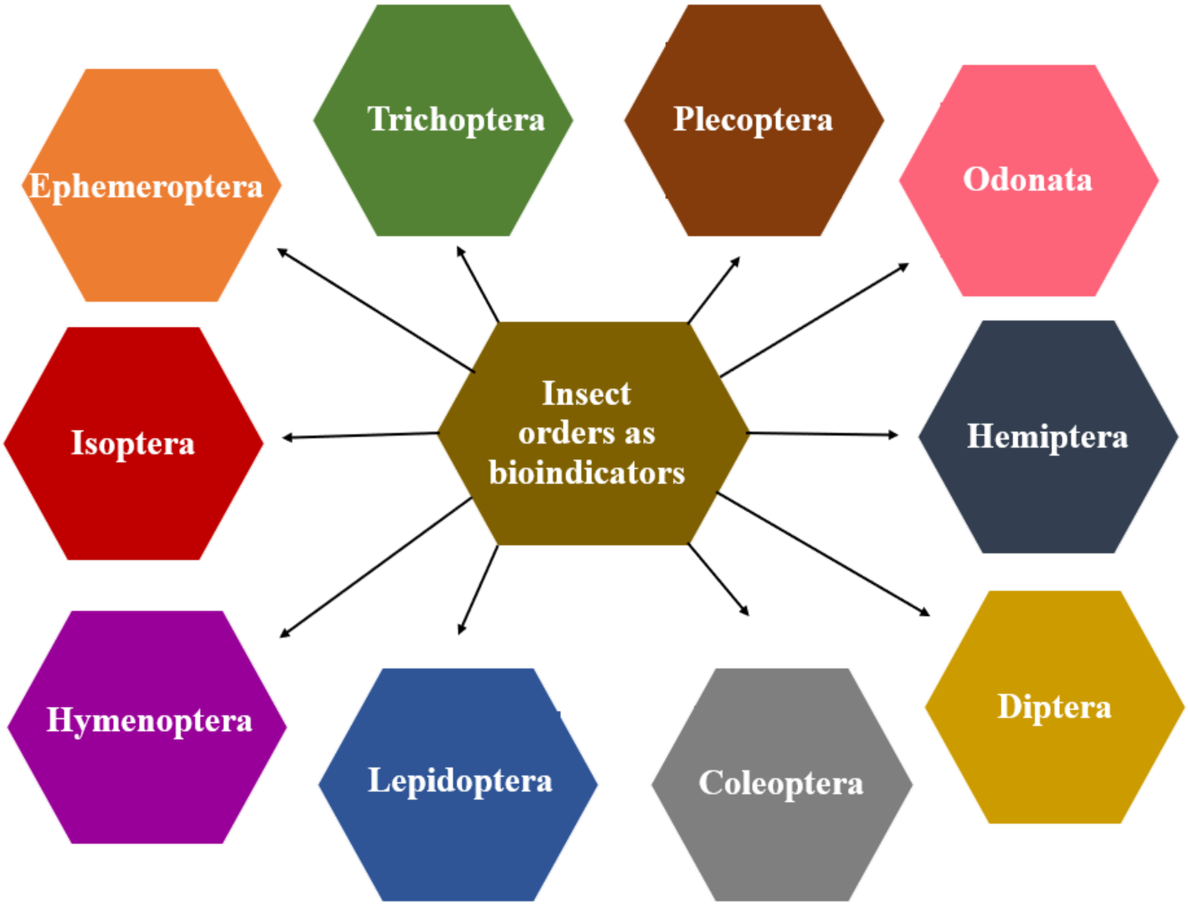

Fig 1: Major insect orders as bioindicators

2. Trichoptera: Caddisflies are aquatic insects whose larvae develop and thrive in freshwater habitat. They are widely used as bioindicators because their presence or absence reflects the ecological quality of water bodies. Changes in the diversity of caddisflies indicated ecological disturbances like deforestation, sedimentation and eutrophication.

Caddisfly nymph and adult

3. Plecoptera: Stoneflies larvae spend most of their life in cold, clean and well-oxygenated water. They are sensitive to siltation, low dissolved oxygen and rise in temperature. The presence of stoneflies indicates the good quality of water as the larval period last for long time.

Stonefly nymph and adult

4. Odonata: It comprises dragonflies (Anisoptera) and damselfly (Zygoptera) are recognized as excellent bioindicators of both aquatic and terrestrial ecosystems. Dragonflies abundance in wetland indicates high water quality as their naiad development requires

Dragonfly naiad and adult

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clean water, while adult dragonflies and damselfly respond quickly to changes in their habitat and vegetation loss.

5. Orthoptera: Orthopterans plays a major role in food web and are excellent bioindicators of environmental changes because of their high sensitivity to habitat fragmentation, climate change and land use patterns.

Grasshopper

6. Hemiptera: Aquatic hemipterans such as Belostomatidae (Giant water bugs), Nepidae (water scorpions) and Gerridae (Water striders) are used to assess the water quality. Terrestrial hemipteran aphid (Aphididae) are great pollution indicators, because their population increases when they feed on the host in carbon dioxide rich environment.

Giant water bug and pond striders

7. Collembola: Collembolans are tiny soil dwelling insects that plays a crucial role in nutrient cycling and decomposition. They are indicators of soil health and ecosystem quality. Springtails are sensitive to chemical pollutants, heavy metals, pesticides and industrial contamination. Decline in their population signals the soil contamination and ecological stress.

Spring tails

8. Diptera: The order of true flies includes mosquitoes, crane flies, black flies, syrphids, chironomids, fruit flies, serve as important bioindicators due to their wide ecological range and varying tolerance to pollution. The maggots of the blackflies (Simuliidae) and crane flies (Tipulidae) inhabit a wide variety of aquatic and semi-aquatic condition but thrives only in clean, well oxygenated stream reflecting good water quality, in contrast maggots of midges (Chironomidae) and mosquitoes (Culicidae) thrive in nutrient rich or low oxygenated water, indicating the eutrophication. Hover flies (Syrphidae) through their diversity reflects habitat quality, floral diversity and landscape structure and acts as indicators of biodiversity loss and ecological balance. *Drosophila melanogaster* (Drosophilidae) acts as bioindicators in open condition.

Syrphid, Mosquito pupa (tumbler) and Chironomid

9. Coleoptera: Coleopterans are one of the most diverse and widespread insect groups. They are excellent environmental monitors mainly in assessing the pollution and forest management. Carabidae (Ground beetles) excellent terrestrial predators are indicators of agricultural crops and forest areas and involved in monitoring of pollutant from oil, sulfur, herbicides, Co2, insecticides and radioactive phosphorus. Their population decline indicates soil degradation and pesticide contamination. Tenebrionidae (Darkling beetles) shows changes in their ovarian tissues due to accumulation of heavy metals (Cadmium, zinc, copper and lead). Scarabaeidae (dung beetles) are bioindicators of habitat fragmentation. Their abundance decreases with habitat degradation, deforestation and over grazing.

Ground beetle and dung beetle

10. Lepidoptera: Butterflies and moths are bioindicators of climatic change, habitat quality, light pollution and sound pollution. Variation in their egg laying site and rates, larval growth and development and survival rate are influenced by temperature changes. Higher diversity if butterflies indicate well preserved habitats whereas the habitat fragmentation shows decline in population. They also act as indicators of environmental contamination with heavy metals. Butterflies rely mainly

Butterfly

on visual and chemical cues for feeding, mating and navigation. Excessive noise disturbs and interferes with their normal behaviour leading to decrease in population. Continuous exposure of butterflies to light pollution disrupts their normal biological cycle resulting in reduced population.

11. Hymenoptera: Honeybees (Apidae) are regarded as bioindicators and bio monitors of environmental quality as they are adapted to a wide range of environmental condition. The reduction in the bee population, changes in their colony strength, foraging pattern indicates the presence or accumulation of pesticides, heavy metals and air pollutants. Ants (Formicidae) are used as environmental indicators in different ecosystems. They are highly sensitive to ecosystem disturbances caused by forest thinning, over-grazing, species invasion, forest fires, forest fragmentation, anthropogenic disturbances and heavy metal contamination. They also act as assessment system in agriculture-ecosystem.

Honey bee

12. Isoptera: Termites are good bioindicator of soil fertility. They thrive in underground nests and their presence can be identified if they cause any damage to plants. Change in the abundance and diversity of termites indicates environmental stress or disturbance. Termites also have association with heavy metal contaminants.

Termites

CONCLUSION

Insects with their incredible diversity and sensitivity to environmental changes, serves natural bioindicator brigade. From the tiniest soil-dwellers to aerial flyers, each of them provides unique clues about the ecosystem health. By observing their presence, behaviour, population diversity, we can detect pollution, habitat loss and climate stress. It is important to protect them that helps us in monitoring and maintaining a healthy environment. Protecting insects means safeguarding environment and ultimately humans.

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HARVESTING CARBON: SUSTAINABLE FARMING SOLUTIONS FOR ARID REGIONS

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Abstract:
Arid and semi-arid areas are defined by low rainfall, poor soil fertility, and harsh climatic conditions, which result in low agricultural productivity and undermine long-term sustainability. Carbon harvesting via sustainable agriculture is a revolutionary approach to arid areas, with the aim of enhancing soil health and biodiversity and addressing climate change by sequestering atmospheric carbon in plants and soil. This strategy targets sequestration of atmospheric carbon dioxide in a sustainable manner using practices including conservation tillage, crop diversification, agroforestry, water conservation, organic amendments, and no-till agriculture in a combined effort to make farms drought- and climate-stable. In contrast, the use of renewable energy technologies, precision irrigation, and drought-tolerant crop varieties maximizes resource utilization while reducing environmental degradation. Carbon farming in drylands is a strategy for improving agricultural productivity and livelihoods. Therefore, carbon farming provides a sustainable means of attaining agricultural resilience and ecological equilibrium in water-scarce environments.

Keywords: Arid regions, Carbon farming, Sustainable agriculture, Soil carbon sequestration, Agroforestry, Climate change mitigation, Drought resilience, Ecological sustainability.

Introduction:

Semi-arid and arid areas are the most stressed ecosystems in the world, with low and unpredictable rainfall, high temperatures, and low soil fertility. These environmental limitations strongly curtail crop production, restrict plant growth, and compromise the sustainability of agricultural systems. With climate change worsening drought frequency and accelerating land degradation, farmers in these areas are increasingly struggling to sustain soil productivity and ensure food security. Traditional farming methods normally accelerate soil erosion and nutrient loss, and decrease agricultural productivity. To avoid these problems, sustainable alternative methods are needed. Carbon farming is a climate – smart and sustainable method that focuses on carbon sequestration and enhances agricultural productivity. This method not only reduces greenhouse gas emissions but also improves the functioning of degraded lands and enhances ecosystem functions. The incorporation of practices such as conservation tillage, agroforestry, water management, organic manure application, and crop diversification aims to replenish soil fertility and improve water retention, which directly counteracts the inherent limitations of arid environments. Harvesting carbon through sustainable agriculture provides a path toward climate resilience and arid land ecological restoration. By converting poor soils into sinks for carbon, farmers can at the same time counteract climate change, enhance soil fertility, and ensure future livelihoods.

Importance of Carbon Farming in Arid Ecosystems:

Drylands, which cover nearly 68% of the entire geographic area (Singh *et al*.,2004) and provide livelihoods to millions of small-holder farmers (Bhattacharyya *et al*., 2023), hold enormous potential for carbon sequestration (Stringer *et al*.,2012). They are increasingly exposed to land degradation, loss of soil organic carbon stocks, and erratic rainfall. Soil deterioration diminishes the capacity of the soil to sequester carbon and retain water, leading to further loss of productivity and food security. The potential for increased dryland crop yields in India has been estimated to reach as high as 170 kg/ha per unit tonne of soil organic carbon sequestered (Srinivasarao *et al*., 2019). Improving soil health is one of the possible benefits of carbon farming in the drylands of India. Improving soil organic matter through conservation tillage, cover crops, and agroforestry can improve the soil's water holding capacity, improve soil structure, and improve nutrient retention. Choosing drought-tolerant cover crops, adopting efficient irrigation technologies, and promoting the judicious use of water are among the most crucial strategies for successful carbon farming in rainfed areas. Further, proper verification as well as monitoring of soil carbon sequestration must be assured to pave the way towards farmer's involvement in new carbon credit as well as trade schemes

Mechanisms of carbon sequestration in agriculture:

The sequestration of carbon in drylands occurs both biologically and physiochemically, sequestering carbon dioxide (CO_2) found in the atmosphere and entrapping it within the soil as plant tissues. Plants absorb CO_2 in these regions during photosynthesis, wherein carbon is sequestered in the form of organic carbon compounds into plant structures such as roots, stems, and foliage leaves (Lal, 2020). During the decomposition of plant roots and plant residues, some of this organic matter becomes a part of the soil in the form of soil organic carbon (SOC). This maintains soil fertility and enhances soil-water-holding capacity, both of which are imperative under rainfed conditions. This action is encouraged through management that involves agroforestry, conservation tillage, and cover crops through the delivery of additional organic inputs to the soil, along with minimizing soil disturbance (Paustian *et al.*, 2019). Furthermore, soil microbial processes help in the conversion of organic residues to stable humus, where carbon is sequestered into the soil structure (Lal, 2018). The carbon sequestration potential of drylands generally depends on vegetation cover, soil texture, available moisture, and land management. Through the integration of unsustainable land management strategies, such as organic inputs, drought-tolerant crops, and reduced soil disturbance, farmers can encourage carbon storage.

Practices to increase carbon sequestration:

1. **Conservation tillage and no till farming:**
   Conservation tillage reduces soil disturbance, promoting the buildup of organic matter and decreasing carbon loss by oxidation (Lal, 2020). No-till farming sequesters soil carbon and increases the stability of soil aggregates, boosting water penetration and resistance to dryness. CA also plays a significant role in reducing greenhouse gas (GHG) emissions from farming. The application of minimum tillage and the use of cover crops enhance soil carbon sequestration, thus avoiding CO_2 release into the atmosphere.
2. **Agroforestry and Crop diversification:**
   Agroforestry systems integrate deep-rooted trees and perennial plants with annual crops, which contribute significantly to long-term soil and plant carbon storage. Trees capture atmospheric CO_2 during photosynthesis, and carbon is stored in their trunks, branches, roots, and leaves. In addition, tree root biomass supplies the soil with organic material that anchors the soil structure together with SOC stability. Crop diversification strengthens climate variability resistance, stabilizes yields, and supports long-term carbon sequestration in the soil.
3. **Organic amendments and composting:**
   The use of organic manure, compost, and biochar injects carbon into the soil with no additional dependency on inorganic fertilizers. They enhance soil microbial diversity and fertility, which translates into increased root development and water-holding capacity. Conventional farming is the highest source of GHG emissions; the use of organic farming will increase soil carbon sequestration and reduce carbon footprints
4. **Watershed and water management:**
   In dryland environments, sound watershed management is essential for reducing carbon footprints by conserving water, encouraging vegetative cover, conserving soil, and implementing sustainable land use that restores ecological balance. Drip and sprinkler precision irrigation systems minimize water loss and ensure maximum water retention in the soil for microbial life and carbon sequestration (FAO, 2022). The use of renewable energy, including solar-powered irrigation, minimizes carbon footprints and promotes sustainability (IPCC 2021).

Socio-economic and policy dimensions:

Efficient carbon farming requires enabling policies and incentives. Financial instruments, such as carbon credits and pay-for-ecosystem-services, encourage farmers to produce sustainable practices by providing economic incentives to sequester carbon (Reed *et al.*, 2020). Training, capacity building, and people-centered programs enhance local people's understanding of soil health and carbon management (UNCCD, 2022). Moreover, the integration of indigenous ecological understanding with high-end technologies can improve the responsiveness of dryland farmers and sustainability in the long run.

Challenges and future prospects:

Carbon farming in drylands faces various challenges, such as the high cost of implementation, limited technical know-how, and limited access to carbon markets (Smith *et al*., 2020). Soil verification and monitoring systems are also weak worldwide, making it difficult to accurately quantify the extent of carbon sequestration (Lal, 2020). In the future, projects will need to address the adoption of digital technologies, remote sensing, and easy-to-use carbon accounting systems to enhance transparency and scalability. Projects will also need to address farmers' research as well as policy alignment across governments, NGOs, and scientific entities to encourage high adoption and realize tangible climate benefits.

Conclusion:

In semi-arid and arid areas, where agricultural productivity is constrained by water shortages, soil erosion, and climatic stresses, carbon farming provides a viable avenue for climate resilience and ecological rejuvenation. Farmers can increase soil fertility while sequestering carbon by adopting sustainable means, such as conservation agriculture, no-till agriculture, agroforestry, and optimal water management. These methods help develop healthier soils that can hold water, harbor biodiversity, and serve as long-term sinks for carbon. The use of organic amendments, cover crops, and drought-resistant crops further enhances the ability of dryland soils to sequester carbon and maintain farm production under new climatic conditions. Additionally, precision irrigation and renewable energy technologies maximize resource use and reduce greenhouse gas emissions, striking a balance between productivity and environmental management.

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KCC Empowers the Rural Economy

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The Kisan Credit Card (KCC) is a tool designed to uplift the rural economy by providing timely, affordable, and flexible credit to farmers. By offering institutional finance, it helps farmers move away from high-interest informal loans and empowers them to manage their agricultural cycles more effectively.

The Kisan Credit Card (KCC) scheme is a government initiative in India that provides farmers with timely and affordable credit to meet their agricultural needs. The scheme was introduced in 1998 by the National Bank for Agriculture and Rural Development (NABARD) to provide a single-window credit facility with simplified procedures. The KCC Scheme was introduced with the objective of providing adequate and timely credit to the farmers for their agricultural operations. The Government of India provides interest subvention of 2% and Prompt Repayment Incentive of 3% to the farmers, thus making the credit available at a very subsidized rate of 4% per annum.

The scheme was further extended for the investment credit requirement of farmers viz. allied and non-farm activities in the year 2004 and further revisited in 2012 by a working Group under the Chairmanship of Shri T. M. Bhasin, CMD, Indian Bank with a view to simplify the scheme and facilitate issue of Electronic Kisan Credit Cards. The scheme provides broad guidelines to banks for operationalizing the KCC scheme. Implementing banks will have the discretion to adopt the same to suit institution/location-specific requirements.

How the KCC empowers the rural economy

The KCC acts as a powerful instrument for rural economic upliftment by facilitating critical investments and providing a financial safety net.

Supports agricultural production and investment

- **Affordable and timely credit:** The KCC provides access to low-interest loans, with an additional interest subvention for timely repayment, reducing the financial burden on farmers. This allows them to purchase essential inputs like seeds, fertilizers, and pesticides at the start of the crop season.
- **Expansion beyond crop cultivation:** The scheme has been expanded to include allied activities such as animal husbandry, dairying, and fisheries. This diversification helps farmers develop multiple income streams, leading to greater financial stability.
- **Investments in farm assets:** Farmers can use the credit to invest in long-term assets like farm equipment, land development, and minor irrigation, increasing their overall productivity and efficiency.

Objective / Purpose

The Kisan Credit Card scheme aims at providing adequate and timely credit support from the banking system under a single window with the flexible and simplified procedures to the farmers for their cultivation and other needs as indicated below:

1. To meet the short term credit requirements for the cultivation of crops;
2. Post-harvest expenses;
3. Produce marketing loan;
4. Consumption requirements of farmer household;
5. Working capital for maintenance of farm assets and activities allied to agriculture;
6. Investment credit requirement for agriculture and allied activities

Type of Card:

- A magnetic stripe card with PIN (Personal Identification Number) with an ISO IIN (International Standards Organization International Identification Number) to enable access to all banks ATMs and micro ATMs
- In cases where the Banks would want to utilize the centralized biometric authentication infrastructure of the UIDAI (Aadhaar authentication), debit cards with magnetic stripe and PIN with ISO IIN with biometric authentication of UIDAI can be provided.
- Debit Cards with magnetic stripes and only biometric authentication can also be provided depending on the customer base of the bank. Till such time, UIDAI becomes widespread, if the banks want to get started without inter-operability using their existing centralized bio metric infrastructure, banks may do so.
- Banks may choose to issue EMV (Europay, MasterCard and VISA, a global standard for the interoperation of integrated circuit cards) and RUPAY compliant chip cards with magnetic stripe and pin with ISO IIN.
- Further, biometric authentication and smart cards may follow the common open standards prescribed by IDRBT and IBA. This will enable them to transact seamlessly with input dealers and also enable them to have the sales proceeds credited to their accounts when they sell their output at mandies, procurement centres, etc.

Delivery Channels:

The following delivery channels shall be put in place to start with so that the Kisan Credit Card is used by the farmers to effectively transact their operations in their KCC account.

1. Withdrawal through ATMs / Micro ATM
2. Withdrawal through BCs using smart cards.
3. PoS machine through input dealers
4. Mobile Banking with IMPS capabilities / IVR
5. Aadhaar enabled Cards

Benefits:

Fixation of credit limit/Loan amount

1. **The short-term limit to arrive for the first year: For farmers raising a single crop in a year:** Scale of finance for the crop (as decided by District Level Technical Committee) x Extent of area cultivated + 10% of limit towards post-harvest / household/consumption requirements + 20% of limit towards repairs and maintenance expenses of farm assets + crop insurance, PAIS & asset insurance.
2. **Limit for second & subsequent year**: First-year limit for crop cultivation purposes arrived at as above plus 10% of the limit towards cost escalation/increase in the scale of finance for every successive year (2nd, 3rd, 4th and 5th year) and estimated Term loan component for the tenure of Kisan Credit Card, i.e., five years.
3. **For farmers raising more than one crop** in a year, the limit is to be fixed as above depending upon the crops cultivated as per the proposed cropping pattern for the first year and an additional 10% of the limit towards cost escalation/increase in the scale of finance for every successive year (2nd, 3rd, 4th and 5th year). It is assumed that the farmer adopts the same cropping pattern for the remaining four years also. In case the cropping pattern adopted by the farmer is changed in the subsequent year, the limit may be reworked.
4. **Term loans for investments** towards land development, minor irrigation, purchase of farm equipment and allied agricultural activities. The banks may fix the quantum of credit for the term and working capital limit for agricultural and allied activities, etc., based on the unit cost of the asset/s proposed to be acquired by the

farmer, the allied activities already being undertaken on the farm, the bank's judgment on repayment capacity vis-a-vis total loan burden devolving on the farmer, including existing loan obligations.

5. **The long-term loan limit** is based on the proposed investments during the five-year period and the bank's perception of the repaying capacity of the farmer
6. **Maximum Permissible Limit**: The short-term loan limit arrived for the 5th year plus the estimated long-term loan requirement will be the Maximum Permissible Limit (MPL) and treated as the Kisan Credit Card Limit.
7. **Fixation of Sub-limits for other than Marginal Farmers:**

- **Short-term** loans and term loans are governed by different interest rates. Besides, at present, short-term crop loans are covered under Interest Subvention Scheme/ Prompt Repayment Incentive scheme. Further, repayment schedules and norms are different for short-term and term loans. Hence, in order to have operational and accounting convenience, the card limit is to be bifurcated into separate sub-limits for short-term cash credit limit cum savings account and term loans.
- The **drawing limit** for short-term cash credit should be fixed based on the cropping pattern and the amounts for crop production, repairs and maintenance of farm assets and consumption may be allowed to be drawn at the convenience of the farmer. In case the revision of the scale of finance for any year by the district-level committee exceeds the notional hike of 10% contemplated while fixing the five-year limit, a revised draw able limit may be fixed and the farmer is advised about the same. In case such revisions require the card limit itself to be enhanced (4th or 5th year), the same may be done and the farmer be so advised. For term loans, instalments may be allowed to be withdrawn based on the nature of the investment and the repayment schedule drawn as per the economic life of the proposed investments. It is to be ensured that at any point in time, the total liability should be within the drawing limit of the concerned year.
- Wherever the card limit/liability so arrived warrants additional security, the banks may take suitable collateral as per their policy.

Eligibility

1. Farmers - individual/joint borrowers who are owner cultivators;
2. Tenant farmers, oral lessees & share croppers;
3. Self Help Groups (SHGs) or Joint Liability Groups (JLGs) of farmers including tenant farmers, share croppers etc

Application Process

- Visit the website of the bank you wish to apply for the kisan credit card scheme.
- From the list of options, choose the Kisan Credit Card.
- On clicking the option of 'Apply', the website will redirect you to the application page.
- Fill the form with the required details and click on 'Submit'.
- On doing so, an application reference number will be sent. If you are eligible, the bank will get back to you for the further process within 3-4 working days.

Documents Required

- Application Form.
- Two Passport Size Photographs
- ID proof such as Driving License / Aadhar Card / Voter Identity Card / Passport.
- Address Proof such as Driving License, Aadhar Card.
- Proof of landholding duly certified by the revenue authorities.
- Cropping pattern (Crops grown) with acreage.
- Security documents for loan limit above Rs.1.60 lakhs / Rs.3.00 lakhs, as applicable.
- Any other document as per sanction.

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Role of Cytoplasmic Male Sterility in Hybrid Seed Production

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Introduction:

Cytoplasmic male sterility (CMS) is a maternally inherited trait in plants where the plant is unable to produce functional pollen, caused by mutations in the mitochondrial genome. This condition arises from a specific interaction between the cytoplasm (mitochondria) and the nuclear genes, and because the cytoplasm comes from the egg, the progeny of a male-sterile plant are typically also male-sterile. CMS is widely used in breeding for creating hybrid seeds in crops like rice and corn, because it facilitates cross-pollination and the resulting hybrids often exhibit increased vigor (hybrid vigor). Hybrid production requires a plant from which no viable male gametes are introduced. This selective exclusion of viable male gametes can be accomplished via different paths. One path, emasculation is done to prevent a plant from producing pollen so that it can serve only as a female parent. Another simple way to establish a female line for hybrid seed production is to identify or create a line that is unable to produce viable pollen. Since a male-sterile line cannot self-pollinate, seed formation is dependent upon pollen from another male line. Cytoplasmic male sterility is also used in hybrid seed production. In this case, male sterility is maternally transmitted and all progeny will be male sterile. These CMS lines must be maintained by repeated crossing to a sister line (known as the maintainer line) that is genetically identical except that it possesses normal cytoplasm and is therefore male-fertile. In cytoplasmic–genetic male sterility restoration of fertility is done using restorer lines carrying nuclear genes. The male-sterile line is maintained by crossing with a maintainer line carrying the same nuclear genome but with normal fertile cytoplasm.

Key features of cytoplasmic male sterility

- **Maternal inheritance:**

CMS is passed down from the mother, as the offspring inherits the cytoplasm from the egg cell.

- **Mitochondrial genes:**

The sterility is due to mutations in the mitochondrial DNA, which are not passed down from the male parent.

- **Nuclear interaction:**

Nuclear genes can either cause the sterility or, in "restorer" lines, suppress the sterility and restore fertility.

- **Hybrid seed production:**

CMS is a valuable tool for producing hybrid seeds because it prevents self-pollination, forcing the plant to cross-pollinate with another line.

- **Hybrid vigor:**

The resulting hybrids often show improved traits, such as higher yields, a phenomenon known as hybrid vigor.

- **Stable trait:**

CMS is generally stable and not affected by environmental conditions.

Applications in agriculture

- **Hybrid crops:**

CMS has been instrumental in developing high-yielding hybrid crops like rice, corn, and cotton.

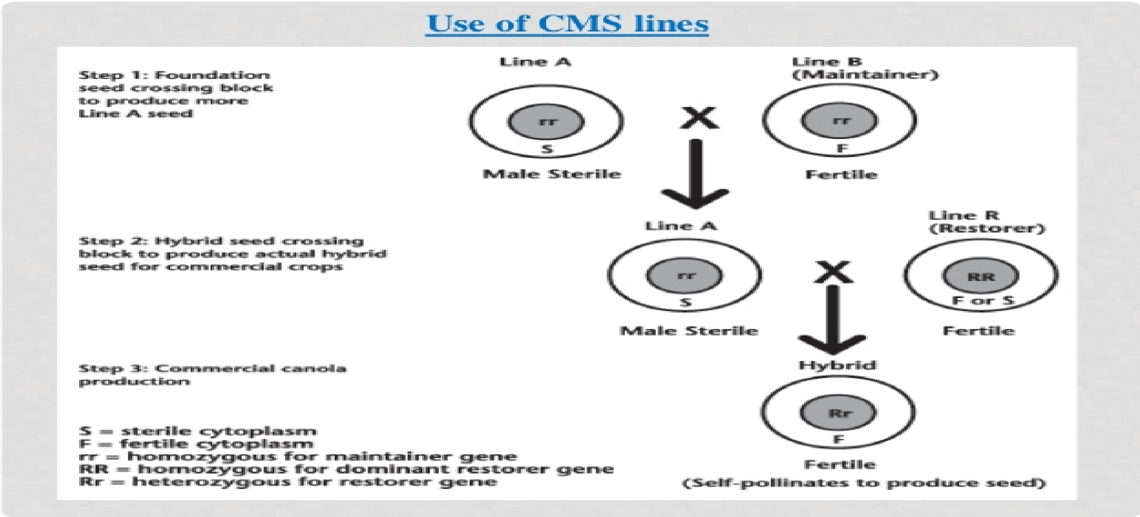
- **Efficient cross-pollination:**

By rendering a line male-sterile, it can be used as the female parent in a controlled cross, ensuring that the resulting seeds are hybrids.

- **Improving yield:**

CMS-based hybrid systems have contributed to significant increases in crop yields, helping to meet the food demands of a growing global population.

Cytoplasmic male sterility (CMS) is crucial for hybrid seed production because it eliminates the need for manual pollination by creating a male-sterile parent (A-line) that cannot produce pollen. This allows for cost-effective, large-scale production of hybrid seeds by crossing the male-sterile A-line with a fertile restorer-line (R-line). The hybrid offspring are fertile, and the CMS trait is maintained for the next generation by crossing the A-line with a maintainer line (B-line).



How CMS is used in hybrid seed production:

❖ **A-line (Male sterile line):**

This is the female parent and is incapable of producing viable pollen due to a mitochondrial trait.

❖ **B-line (Maintainer line):**

This is a male-fertile line that is genetically identical to the A-line except for its male fertility. It is used to maintain and multiply the A-line by crossing with the A-line, which produces more male-sterile plants for the next cycle.

❖ **R-line (Restorer line):**

This line contains a nuclear gene (Rf) that restores fertility to the male-sterile A-line.

❖ **Hybrid seed production:**

The A-line is crossed with the R-line to produce fertile F1 hybrid seeds. The R-line pollinates the A-line, and since the A-line is sterile, all seeds produced will be from the cross with the R-line.

❖ **Cost-effectiveness:**

Using CMS drastically reduces the costs associated with hybrid seed production by eliminating the need for manual emasculation (removal of anthers).

Importance of CMS

❖ **Uniformity:**

CMS provides a genetic system to produce large populations of male-sterile plants, which is more efficient than manually emasculating every plant.

❖ **Heterosis:**

By creating a controlled cross between two distinct lines, CMS allows breeders to harness heterosis (hybrid vigor) for improved yield and other desirable traits in the hybrid offspring.

❖ **Versatility:**

The system is used in many crops, especially those where the seed is the economic part, like corn, sorghum, and some vegetables. In vegetables where the vegetative part is valued (e.g., onion, carrot), CMS is also beneficial.

Limitations of CGMS

- Undesirable effects of the cytoplasm
- Unsatisfactory fertility restoration
- Unsatisfactory pollination

- Spontaneous reversion
- Modifying genes
- Contribution of cytoplasm by male gamete
- Environmental effects
- Non availability of suitable restorer line

Advantages of CGMS

- Hybrid seed production. E.g.: maize, rice etc.
- Convenience of controlling sterility expression by manipulating the gene-cytoplasm combinations in any selected genotype.
- Facilitate cross breeding producing only hybrid seeds under natural conditions.
- Saves lot of time money and labour.

Key roles of male sterility

- **Cost and labor reduction:**

Without male sterility, the laborious process of emasculation (removing the male parts of the flower) must be done manually. Male sterile lines make this unnecessary, significantly lowering the cost and labor involved in hybrid seed production.

- **Ensuring high hybrid purity:**

The female parent's inability to produce viable pollen guarantees that all seeds produced are the result of a cross-pollination between the female and male parents. This results in high-purity hybrid seeds with consistent traits.

- **Enabling heterosis:**

Male sterility is a key tool for exploiting heterosis, the phenomenon where the hybrid offspring exhibits superior performance over its parents. By facilitating the creation of hybrids, male sterility helps unlock the genetic potential for increased yield, quality, and stress resistance in crop varieties.

- **Facilitating different systems:**

Various genetic systems, including cytoplasmic male sterility (CMS), genetic male sterility (GMS), and cytoplasmic-genetic male sterility (CGMS), provide flexibility for different crops to create hybrid seeds.

- **Maximizing female parent yield:**

Manual emasculation can sometimes damage the female plant, reducing its seed yield potential. Using male sterility eliminates this risk and allows the female plant to achieve its full seed yield potential

Cytoplasmic male sterility (CMS) is determined by the cytoplasm and is useful for hybrid seed production but limits the hybrids to being male sterile. Maintaining male sterile lines requires A, B, and R lines. Male sterility reduces the cost and effort of hybrid seed production.

Male sterility is a key tool in hybrid seed production, as it eliminates the need for manual emasculation, significantly reducing labor costs and increasing efficiency for large-scale production. It ensures that the female parent cannot self-pollinate, forcing cross-pollination with the male parent to produce hybrid seeds with desirable traits like high yield and disease resistance. This method is commercially exploited through systems like cytoplasmic male sterility (CMS) and cytoplasmic genetic male sterility (CGMS) in crops like onions, carrots, and cabbage. Male sterility is essential for hybrid seed production because it prevents self-pollination, making cross-pollination necessary and ensuring that the resulting hybrid seeds are pure. It significantly reduces the cost and labor of producing hybrid seeds by eliminating the need for manual emasculation, which is especially beneficial for crops with small flowers. This allows for efficient and economical large-scale F1 hybrid seed production, which boosts the efficiency and commercial viability of hybrid crops.

Advances in male sterility for hybrid seed production have accelerated efficiency through biotechnological tools like CRISPR-Cas9 for gene editing and the development of novel techniques such as chromosome engineering and pollen cryopreservation. These methods allow for the creation of sterile lines and hybrids more rapidly, enable the use of diverse parent lines, and improve the efficiency of hybrid breeding by providing tools for faster development, genetic purity testing, and overcoming the limitations of traditional systems like cytoplasmic male sterility (CMS). The overall conclusion is that these advancements, particularly genomic and biotechnological approaches, are crucial for enhancing crop yields, genetic diversity, and adaptability to diverse environments, while also addressing challenges like instability and genetic vulnerabilities associated with older methods.

Key advancements and their impacts

Biotechnology:

- **CRISPR-Cas9 and gene editing:** Directly manipulate male sterility-associated genes to create male-sterile lines more efficiently.
- **RNA interference:** Another tool to manipulate genes for male sterility.

Genomic and genetic tools:

- **DNA markers:** Facilitate the rapid development of restorer lines and the testing of genetic purity in hybrids.
- **Genomic prediction:** Allows for more efficient construction of heterotic pools and identification of heterotic patterns.
- **Epigenetic studies:** Provide a deeper understanding of how epigenetic changes affect hybrid vigor and fertility restoration.

Pollen cryopreservation:

- Enables the storage and use of viable pollen across seasons and geographic locations.
- Helps overcome challenges like flowering time synchronization and facilitates hybridization across different genera and species.

Chromosome engineering:

- Can be used to create male-sterile lines more rapidly than conventional methods.

Modern CMS/GMS systems:

- More advanced CMS/GMS systems can be developed, offering more stability and better control over male sterility.
- Environment-sensitive male sterility (EGMS) mutants offer flexibility by allowing fertility to be restored under different growth conditions.

These advances ares that while traditional methods like CMS are still valuable, they are being significantly enhanced and in some cases replaced by modern biotechnology and genomic tools. These newer technologies are crucial for overcoming the limitations of older methods, improving efficiency, and ultimately accelerating the development of high-performing hybrid varieties needed to address global food security challenges.

Conclusion:

Male sterility is crucial for hybrid seed production because it acts as a natural genetic tool that eliminates the need for manual emasculation (detasseling) of the female parent, making hybrid seed production more cost-efficient and effective. By ensuring the female parent cannot self-pollinate, it forces cross-pollination with the male parent, which guarantees the high-yielding and vigorous F1 hybrid seeds for which it was designed. Conclusion: Male sterility is an indispensable component for commercial hybrid seed production, enabling the efficient and economical creation of superior-quality hybrid varieties with enhanced yield, disease resistance, and early maturity. The conclusion from these advances is that while traditional methods like CMS are still valuable, they are being significantly enhanced and in some cases replaced by modern biotechnology and genomic tools. These newer technologies are crucial for overcoming the limitations of older methods, improving efficiency, and ultimately accelerating the development of high-performing hybrid varieties needed to address global food security challenges.

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Speed Breeding Exploration in Rice

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To increase rice yields and feed billions of people, it is essential to enhance genetic gains. However, the development of new varieties is hindered by longer generation times and seasonal constraints. To overcome this problem, scientists need to work on new speedy methods of crop improvement. Speed breeding is a modern plant breeding technique that shortens the time needed for a full breeding cycle by controlling environmental conditions, such as providing proper light period, temperature, humidity, light source, and carbon dioxide in controlled environments such as growth chambers. Thus, the Speed breeding technique facilitates 4–5 generations of cop to be grown annually instead of the usual one or two, drastically accelerating the development of new, climate-resilient varieties. Further, speed breeding significantly shortens the time required for genetic research, marker-assisted selection, trait stacking, disease resistance screening, and the introgression of valuable traits into existing crop lines. The concept of speed breeding was inspired by NASA's technology for growing plants in space stations, which used constant light to speed up the growth process. The term "Speed breeding" was coined by researchers at the University of Queensland in 2003.

A scientist named Pfeiffer (1926) cultivated crops under artificial light, *in vitro* conditions by managing light intensity, moisture, temperature, humidity, etc. Plants responded to artificial light with early germination, early flowering, and maturity. NASA (National Aeronautics and Space Administration) and USU (Utah State University) worked together on space crop cultivation using wheat under artificial light. In 1990, LED light was first developed, and its impact on plant growth was studied. The speed breeding concept was first introduced in 2003. In 2016, Queensland University of Australia developed a wheat variety, and CIMMYT developed a wheat variety in 2019. IRRI-Varanasi developed the first rice variety, IR64, under speed breeding.

Speed Breeding Protocol in Rice (SpeedFlower)

Scientists from the International Rice Research Institute (IRRI) developed a robust, first ever speed breeding protocol for rice that will achieve 4 to 5 crops of rice in one year - almost double of what has been possible in breeding programs until now. To achieve speed breeding in rice, the facility has been customized with controlled growth parameters using fully enclosed walk-in growth chambers. SpeedFlower, the protocol focuses on optimizing light spectrum, amount and intensity, along with temperature, humidity and other variables that expedite growth, flowering and maturity in rice. The protocol is suitable for the vast majority of rice grown globally, including for indica and japonica rice. In 2021, IRRI Varanasi developed the first rice variety, IR64 under speed breeding. In this method, they first sown seeds under controlled conditions using LED lamps with a temperature of 22–27 degrees, humidity of 60–70%, and a photoperiod of 22 hours of light and 2 hours of darkness. Plant germination occured within 4 days, flowering initiation occurred within 40–45 days, and the pollination stage is reached at 58–60 days. After pollination, immature seed are harvested within 12–15 days and placed into the oven for drying at 34 degrees Celsius for approximately 3 days. This seed is then used to germinate the next generation. Five to six generations are easily developed in one year.

Components of Speed Breeding

There are four components used in speed breeding: Light**,** Photoperiod**,** Temperature**,** and Humidity**.**

1. **Light**: Light is the most affected factor in speed breeding. Plant germination, flower initiation, photosynthesis, and growth regulation all depend on proper light. In speed breeding, LED lamps and sodium lamps are used for plant growth. Plants easily respond to red, blue, and white light for their growth and development. LED light is more useful in the speed breeding method because it's easily managed and has a low setup cost. No extra skill is required for management. Red light is used for plant germination, and blue light is used for proper plant growth.

2. **Photoperiod**: I Plants' proper growth and development occurs under a specific photoperiod. Some plants need a short-day length, some need a long-day length, and some need a neutral-day length. Due to the photoperiod, chlorophyll activity regulated in the plant. Plants develop food using chlorophyll. Flower initiation, seed setting, and seed maturity are all done through the photoperiod. Through proper light management, one can change plant physiological processes, converting the plant life cycle earlier as compared to *in vivo* conditions. Speed breeding allows us to achieve 5–6 generations per year. The typical photoperiod is 22 hours of light and 2 hours of darkness. Providing a proper photoperiod completes the life cycle within 60–70 days.
3. **Humidity**: Proper management of the humidity level to reduces fungal infection in the plant and decrease the pollen sterility rate. Photosynthesis, leaf growth, and stomatal regulation indirectly impacted by humidity. In speed breeding, the humidity level is approximately 60–70%. More or less humidity can adversely affect plants, leading to fungal and pest development. In speed breeding, a low level of humidity is recommended for dry environmental conditions.
4. **Temperature**: Plant growth and development depend on the type of temperature we can provide. Temperature impacts on seed germination, seed setting, pollination, etc. In the speed breeding method, the temperature is 22–27 degrees Celsius during the day daytime and 17 degrees Celsius during the dark period. After pollination, seed setting occurs within 15 days. The immature seed is harvested and put out for drying to reduce the moisture level at 34 degrees temperature for 3-4 days.

Methods and Rice Specifics

There are three methods used in speed breeding:

1. Controlled Environmental Condition
2. Glass House
3. Homemade LED Light

Controlled Environmental Condition

In this method, the environment is controlled by managing light photoperiod and light intensity. During day time, the photoperiod is 22 hours and the temperature is 22 degrees. During the dark period, the photoperiod is 2 hours and the temperature is set to 17 degrees. This method uses a Conviron BWD chamber. Light intensity is 360–380 umol m^{-2} s^{-1}. This method produces healthy seed, and seed viability is not affected.

Glass House

In this method, crops grown under *in vitro* conditions in a glass house. Lamps are used for providing the light period, such as sodium lamps, fluorescent lamps, LED lamps, and metal halide lamps. Fluorescent lamps provide warm light to create a neutral environment for crop growth. Sodium lamps provide blue to white light, and LED lamps provide red-infrared light. This light is used for easy germination of seed and proper growth.

Homemade LED Light

This method uses only LED light. LED lights provide red to infrared light, which helps plant development. No extra skill is required for management, and the set-up cost is very low. Plant response is positive with this light: germination, growth and development, flowering, seed setting, maturity, and moisture content all are done properly under this method. The plant life cycle is complete within 60–70 days.

Changes in Rice after Speed Breeding

- **Plant height:** Slightly reduced and dwarf**.**
- **Leaf appearance:** Faster and earlier appearance**.**
- **Tiller number:** More as compared to *in vivo* condition, early initiation.
- **Roots:** Faster growth and total biomass reduced.
- **Flowering:** Regular and pollination easy; pollen grain remains viable for a long time.
- **Panicle:** Early emergence**,** slightly smaller in some cases.
- **Seed:** Big**,** bold, and normal in weight, early germination.
- **Harvesting time:** Early as compared to *in vivo* and seed quality is perfect.

Application of Speed Breeding

- Multiple generations per year.
- Rapid development of homogeneous lines through Single Seed Descent (SSD).
- Application of disease resistance genes in the cultivar.

- Maintaining the quality of the seed.
- Rapid search for resistance genes in available germplasm collections.

Benefits of Speed Breeding

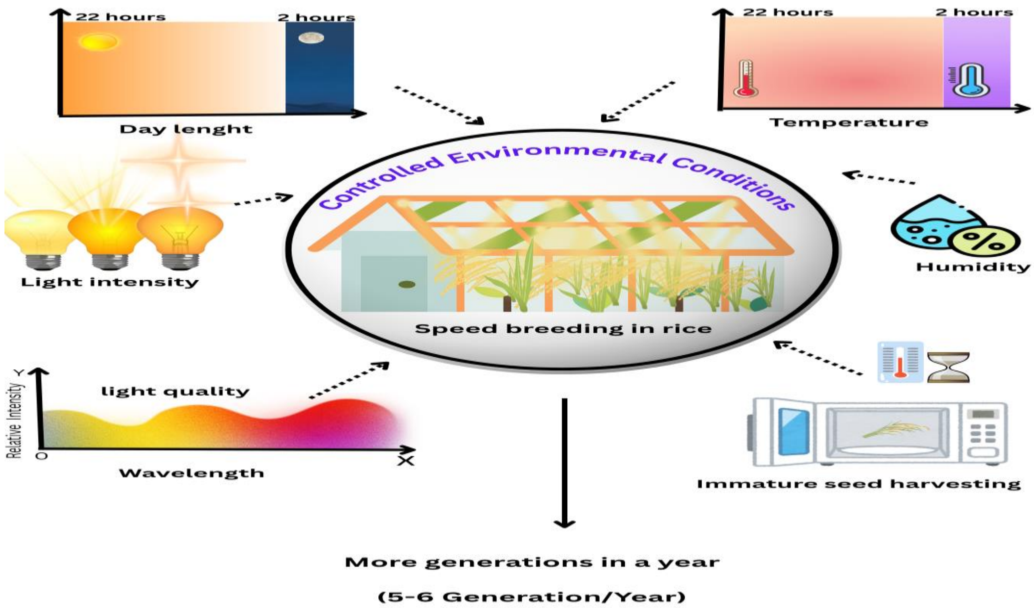
- Reduced breeding cycle.
- Food production related problems are solved.
- Higher quality seed is produced.
- Low-cost setup.
- No skillful people are required for management.

Limitations of Speed Breeding

- The setup cost is higher if a light source other than LED is used, and its management is also difficult.
- A small number of seed is produced.

Key factors of speed breeding, range and effect on the plant

Factor	Range	Plant Effect
Temperature	22-27 degree temperature	Early germination of seed
Photoperiod	Light period -22hr Dark period 2hr	Early flowering and leaf appearance
Light source	LED lamp, sodium lamps, fluorescent lamp	Plant growth and development
Humidity	60-70%	Reduced plant sterility
Co_2	400-600 ppm	Increase biomass level



Generalized overview of the speed breeding technique

Conclusion

In conclusion, speed breeding represents a pivotal and necessary advancement in agricultural science, offering a vital, accelerated pathway to address the pressing challenge of global food security amid a rising population and escalating climate threats. By meticulously controlling the four critical environmental components *viz.*, light, photoperiod, temperature, and humidity, scientists can dramatically shorten the crop lifecycle, achieving five to six generations per year compared to the decades often required by traditional methods. This technology, exemplified by the successful development of the IR64 rice variety by IRRI-Varanasi, is not just a historical curiosity but a modern, scalable tool for rapid crop improvement. Ultimately, speed breeding ensures the faster deployment of new high-yielding, disease-resistant, climate-resilient, and nutritionally superior rice varieties in a much shorter duration, making it an essential technique for safeguarding food supplies and sustaining the next generation.

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Women's Participation and Empowerment in Agrotourism

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Abstract

Agrotourism, an intersection of agriculture and tourism, has emerged as a significant tool for sustainable rural development. Among its many benefits, it provides rural women with opportunities for entrepreneurship, skill development, and socio-economic upliftment. In India, women's involvement in agrotourism has expanded beyond traditional roles, contributing to economic diversification, preservation of rural heritage, and environmental sustainability. Recently, tribal women in Tamil Nadu have also begun engaging in agrotourism initiatives, transforming their traditional practices into viable sources of income and community development. This paper explores the dimensions of women's participation in agrotourism, their empowerment outcomes, challenges faced, and future prospects.

Keywords: Agrotourism, Women Empowerment, Rural Development, Entrepreneurship, Tribal Women, Tamil Nadu, Sustainable Tourism.

Introduction

Agrotourism is an emerging concept that bridges agriculture and tourism to promote rural livelihood diversification. It provides visitors with opportunities to experience authentic farm life while contributing to the local economy. For rural women, agrotourism represents more than just an income source — it serves as a pathway toward economic independence, social recognition, and cultural preservation.

Women, traditionally engaged in agriculture and household activities, are now increasingly recognized as entrepreneurs and innovators in rural tourism. Their contribution is particularly visible in regions such as Maharashtra, Kerala, and Tamil Nadu, where rural and tribal women are leveraging agrotourism to showcase their agricultural practices, handicrafts, cuisines, and ecological knowledge to domestic and international visitors.

Agrotourism represents a growing segment of rural tourism where agricultural activities are combined with tourism to offer visitors unique farm-based experiences. It encourages visitors to experience the lifestyle, traditions, and agricultural practices of rural areas while generating supplementary income for farmers.

Women, who have long been the backbone of agricultural labor, are now emerging as central figures in the agrotourism movement. Their roles have evolved from unpaid agricultural workers to income-generating entrepreneurs, guides, and community leaders. The participation of women, particularly tribal women in Tamil Nadu, marks a pivotal shift in rural economic empowerment and gender equality.

Role of Women in Agrotourism

Women play multifaceted roles in agrotourism that extend beyond hospitality. Women prepare regional cuisine, and create a hospitable environment for tourists. Their warmth and attention to detail make them the backbone of rural hospitality. Tourists often prefer authentic experiences curated by local women who reflect the region's traditions and values.

Women play a significant role in showcasing traditional recipes and farm-to-table experiences. Preparing organic meals, local snacks, and regional delicacies connects visitors with the agricultural identity of the place while generating income for women entrepreneurs. Agrotourism often includes the sale of handmade products such as baskets, clay pots, traditional attire, herbal cosmetics, and organic produce. Women-led cooperatives and self-help groups (SHGs) handle production and marketing, blending traditional craftsmanship with modern business practices.

Women act as cultural ambassadors by organizing folk dances, storytelling sessions, and traditional art displays. These cultural components enrich the tourist experience and help preserve indigenous knowledge and customs. Women are actively involved in eco-tours, farm walks, and organic farming demonstrations. By guiding visitors on sustainable agricultural practices and biodiversity conservation, they promote environmental awareness and climate resilience.

Women-led agrotourism ventures have proven to be successful models of micro-entrepreneurship. They not only generate employment but also inspire other rural women to become self-reliant. Leadership roles in cooperatives and tourism groups enhance their confidence and decision-making abilities.

Women's Empowerment through Agrotourism

Agrotourism empowers women in multiple dimensions:

Economic Empowerment

Women gain financial independence, control over income, and the ability to invest in their families and communities. In many cases, women-led agrotourism ventures have improved household income and reduced migration pressures.

Social Empowerment

Participation enhances women's leadership skills, decision-making abilities, and visibility within the community. It promotes gender equality by recognizing women's potential as entrepreneurs and change-makers.

Cultural and Psychological Empowerment

By sharing their traditional knowledge with tourists, women gain confidence and pride in their heritage. They become active cultural ambassadors, ensuring the intergenerational transmission of indigenous practices.

Case Example: Tribal Women in Tamil Nadu

In recent years, tribal women from regions such as the Nilgiris, Erode, and Dharmapuri districts of Tamil Nadu have ventured into agrotourism. Supported by local NGOs, forest departments, and tourism boards, these women are turning their indigenous skills into income-generating opportunities.

Projects like "Tribal Eco-Agritourism Circuits" promote traditional honey collection, organic spice cultivation, herbal medicine preparation, and nature-based tourism. Women from Irula, Kurumba, and Paniya tribes have been trained in hospitality, eco-guiding, and handicraft production. These initiatives not only enhance their socio-economic status but also contribute to the preservation of tribal heritage and biodiversity conservation.

Moreover, the Tamil Nadu Tourism Development Corporation (TTDC) and Tamil Nadu Rural Transformation Project (TNRTP) have begun to integrate tribal women's cooperatives into rural tourism circuits, fostering inclusive growth and women-led entrepreneurship.

Recent Initiatives: Tribal Women in Tamil Nadu Taking the Lead

In recent years, several tribal women's groups in Tamil Nadu have begun pioneering ventures that connect agrotourism, forest produce, eco-tourism, and livelihood enhancement. These recent cases illustrate not only innovative business models but also how tribal women are gaining greater agency and recognition.

Kani Tribal Women's Startup (Nanjil Kani Women Creators Pvt. Ltd., Kanyakumari)

The Kani women have established a startup to process and sell forest-derived organic products — such as various types of honey, pepper, turmeric — directly to the market, including exploring online platforms. By doing so, they minimize reliance on intermediaries. Their venture got a boost through support from the Tamil Nadu SC/ST Startup Fund. This model shows how tribal women are combining traditional knowledge (forest produce) with modern business practices.

Kattunayakan Women Cooperative in Nilgiris

Women from the Kattunayakan tribe have formed a cooperative to procure, process, package, and sell honey and other forest produce (wild herbs, spices) from surrounding villages. Before the cooperative, price offered to them was low; now, with value-addition and collective marketing, their profit margins are much higher. This venture is helping women gain more financial autonomy and bargaining power.

Genepool Eco Park, Nadugani

Under the Tamil Nadu Biodiversity Conservation & Greening Project, the Genepool Eco Park near Gudalur has increased tribal participation (including women) in eco-tourism related services. Women are involved in preparing food, operating guest services at the park, and running cafés and stay facilities. Over recent years, the number of working tribal people has increased, indicating growing trust and capacity. Income generated has become more substantial and regular.

Aquaculture + Rural/Aqua-Tourism Linkages

At a national workshop in Chennai, examples of tribal (and coastal) women were shared who have benefitted from aquaculture-based livelihood projects. These include technologies like nurseries, value addition of aquaculture produce, and exploration of tourism linkages. The intention is to combine livelihoods and tourism by promoting rural / aqua-tourism opportunities in coastal and tribal districts.

These initiatives show trends of:

- Value addition (packaging, branding) rather than raw commodity sale
- Use of government / NGO support to scale up
- Combining traditional knowledge (forest or coastal) with business & tourism potential
- Women moving into visible roles (guest services, café operations, entrepreneurship) rather than just supporting roles

Challenges Faced by Women in Agrotourism

Despite the progress, several barriers hinder women's full participation:

- Limited access to training, credit, and infrastructure.
- Socio-cultural constraints restricting women's mobility and decision-making.
- Lack of digital literacy and marketing networks.
- Seasonal demand fluctuations and inadequate policy support.
- Limited access to financial credit and property ownership.
- Lack of professional training in hospitality and marketing.
- Socio-cultural restrictions affecting freedom and mobility.
- Poor infrastructure and inadequate promotional support.

Overcoming these barriers requires gender-sensitive policy measures and capacity-building programs.

Policy Recommendations

1. **Capacity Building:** Organize regular training programs in business management, communication, and hospitality.
2. **Financial Inclusion:** Simplify access to microcredit and self-help group (SHG)-based funding.
3. **Institutional Support:** Encourage government-private partnerships for women-led agrotourism projects.
4. **Digital Literacy:** Train women in online marketing, e-booking systems, and social media promotion.
5. **Recognition:** Establish awards and certification systems for outstanding women agrotourism entrepreneurs.

Conclusion

Agrotourism stands as a transformative approach to rural development — not only economically but also socially and culturally. Women, especially tribal women in Tamil Nadu, have demonstrated resilience, creativity, and leadership in this sector. By nurturing their participation through targeted policies, training, and inclusive opportunities, India can create a model of gender-sensitive, sustainable rural tourism that uplifts entire communities. Empowering women in agrotourism is thus not just a developmental goal — it is a step toward achieving holistic sustainability.

Women's participation in agrotourism represents a transformative shift in the rural development landscape. Their leadership fosters economic growth, environmental awareness, and cultural preservation — essential pillars of sustainable tourism. The growing involvement of tribal women in Tamil Nadu serves as an inspiring example of how traditional wisdom can align with modern enterprise.

By nurturing women's roles through training, policy support, and recognition, agrotourism can evolve into a powerful vehicle for inclusive growth and gender equality, ensuring that rural women become architects of their own empowerment and prosperity.

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Amaranthus: Finding the Forgotten Grain

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I have been growing this for the last 40 years' told Bishno Devi when asked for how long she has been growing Amaranthus. Hailing from a remote village *'Chakwa'* in block Batote of district Ramban, she calls its grain as '*Seuol'* which she believes is a holy grain largely consumed during fast and other religious ceremonies. Like Bishno Devi, many other farmers in the Panchayat cultivate Amaranthus. Fields can be seen with a Burgundy boundary of Amaranthus and this gives them a very beautiful and unique look. Amaranth widely recognized name for plant and its seeds is also known as Rajgira, *Chaulai* or Ramdana in Hindi and other Indian languages. The name Rajgira itself mean Royal grain while Ramdana translates to God's Grain reflecting the belief in its divine and nutritious qualities. '*Chaulai'* often refers to its edible leaves.

Amaranthus, a Pseudo millet and regarded as one of the nutri-cereals has very high protein content (13-14%) and is a carrier of lysine, an amino acid that's missing or negligible in many others; this grain has also an oil percentage of 6 to 9% which is higher than most other cereals. Amaranth oil contains approximately 77% unsaturated fatty acids and is high in linoleic acid. It is also high in dietary fibre, iron, magnesium, phosphorus, potassium and appreciable amounts of calcium. Recognizing its importance in the nutritional security, the Ministry of Agriculture and Farmers Welfare, (MoA & FW) GoI has put it under broad category of millets and comprising of Sorghum (Jowar), Pearl Millet (Bajra), Finger Millet (Ragi/Mandua), Minor Millets i.e., Foxtail Millet (Kanngani/kakun), Proso Millet (Cheena), Kodo Millet (Kodo), Barnyard Millet (Sawa/Sanwa/Jhangora), Little Millet (Kutki), Brown top millet and two pseudo millets i.e., Buckwheat (Kuttu) as well as Amaranth (Chaulai)) as 'Nutri-Cereals' for production, consumption and for trade and commerce. This group of crops is gluten free and non-allergenic and non acid forming foods. Their consumption decreases triglycerides and C-reactive protein, thereby preventing cardiovascular disease. All of them are rich in dietary fibre. Dietary fibre has water absorbing and bulking property that increases transit time of food in the gut thereby helping in reducing risk of inflammatory bowel disease and acting as detoxifying agent in the body. Millets act as a probiotic feeding for micro flora in our inner ecosystem. Millets hydrate our colon to keep us from being constipated. Niacin in millet can help lower cholesterol.

The most unfortunate part of agriculture sector in the country is that over its journey of last so many decades, many important and nutritive food grains were lost out to crops lie Maize, Rice and Wheat. This loss can be attributed to a variety of factors. The changing tastes, dietary habits and a policy that did not paid any attention to cultivation and promotion of these crops were the main reasons why crops like pulses, millets and oilseeds lost out to Paddy, Wheat and Maize. This loss has brought with it nutritional insecurity, non remunerativeness, climate change and various other environmental hazards. Studies reveal that Rice and Wheat always do not dominated our plates. Ancient civilizations especially in Asia and Africa thrived on millets. These grains were easy to grow, nutritious and suitable for dry climates. The green revolution in the 1960s in the country primarily focused on cultivation of High yielding varieties of Paddy and Wheat and it resulted in a phenomenal increase in their production which is referred to as the Green Revolution in the country. Thereafter huge investment was made with subsidies in fertilizers and machinery to ensure that a larger area is being brought under their cultivation. While all the focus was on Paddy and Wheat, no such effort was being made for pulses, oilseeds and millets. The result was that the area under these crops went on declining and declining until a few years back government came up with a host of initiatives to promote the cultivation of pulses, millets and oilseeds.

The International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) estimates that more than 90 million people in Africa and Asia depend on millets in their diets and 500 million people in more than 30 countries depend on sorghum as a staple food. In the Indian subcontinent, these are recognized as traditional grains, grown and consumed in the Indian subcontinent from the past more than 5000 years. These are one of the oldest foods known to humanity. Millets owing to their unique characteristics have been identified as a major category of food commodities to be propagated and promoted for enhancing nutritional levels of the population. These groups of small grained cereal food crops which are highly nutritive are also tolerant to drought and other extreme weather condition; do not require much input and most of them are natives of the country. These crops are called as *'Nutri-cereals'* as they provide most of the nutrients required for normal functioning of human body.

A Farm Women with her Amaranthus crop in a remote village *Chakva* in District Ramban

District Ramban in the Union Territory of Jammu and Kashmir is characterized by marginal and small holdings. Only 5-6% of cultivable area is under irrigation and thus cultivation of different crops is dependent upon timely and adequate rainfall. During *Kharif* season crop failure due to poor germination as a result of moisture stress adversely affects the productivity of Maize and other *Kharif* crops. Various type of Millets which once used to grown in this district have now largely been abandoned due to one or other reason. To revive the cultivation of Millets in this district, KVK-Ramban under its '**10% under Millets**' initiative has been motivating the farming community to take on the cultivation of these nutri-cereals. Quality seeds of different type of millets along with sensitization on production technology of millets are being provided to farming community. Although no. of farmers cultivating millets in district are very less, but there are few villages in district where a considerable number of farmers have been cultivating millets for many years. Certain indigenous practices are also being associated with their cultivation. While millets like Finger millet, Little millet and Kodo Millet are being sown in the fields, Amaranthus is sown along the field bunds with main crop (Maize) in the field. In hilly terrains, growing Amaranthus on field bunds offers various advantages. Besides increasing food security and income, it helps in soil health management by controlling soil erosion, increasing biodiversity and enhancing land use efficiency by utilizing marginal spaces for a high yield crop.

Millets are wonder foods but owing to lack of knowledge regarding nutritional value of these crops, these have more or less lost their importance as vital crops. It is high time to promote the cultivation of these crops by educating masses about the health benefits of them. Considering the immense potential of millets in nutritional security and their ability to withstand climatic stress and grow in regions otherwise not feasible for cultivation and with minimal inputs, year 2023 was celebrated as International Year of Millets. There is a need for an urgent and strong push to recognize millets as a vital crop for food security, climate resilience, and nutritional health due to its high protein, fiber, and mineral content, and its ability to grow in challenging conditions like drought and low-fertility soils.

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Role of NANO DAP for increasing fertilizer use efficiency

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Introduction

Indiscriminate use of chemical fertilizer not only increase the cost of cultivation but also destroys soil health. With increase in fertilizer consumption, yield is not increasing, declining nutrient use efficiency and decrease in food grain productivity.

Nano fertilizers are gaining importance in agriculture in increasing crop yields, nutrient use efficiency and reducing excessive usage of chemical fertilizers. Nano DAP is an excellent fit for the idea of sustainable agriculture. It eliminates the demand for chemical fertilisers and promotes prudent nutrient management.

What is Fertilizer Use Efficiency

- Nutrient use efficiency is the output of any crop per unit of the nutrient applied under a specified soil and climatic condition.
- The equation for NUE can be found by dividing grain yield by the total amount of nutrient available to the crop.
- It is a workable indicator to assess and monitor sound fertilizer use.

Challenges facing Indian agriculture:

- ✓ Degradation of soil health.
- ✓ Imbalanced fertilizer use.
- ✓ Slow growth in food grain productivity.
- ✓ Emerging multi-nutrient deficiencies particularly secondary and micro nutrients.

Nano fertilizers:

Nano fertilizer refers to a product that delivers nutrients to crops in one of three ways:

1. The nutrient can be encapsulated inside Nano-materials such as nano tubes or nano porous materials.
2. Coated with a thin protective polymer film.
3. Delivered as particles or emulsions of nanoscale dimensions.

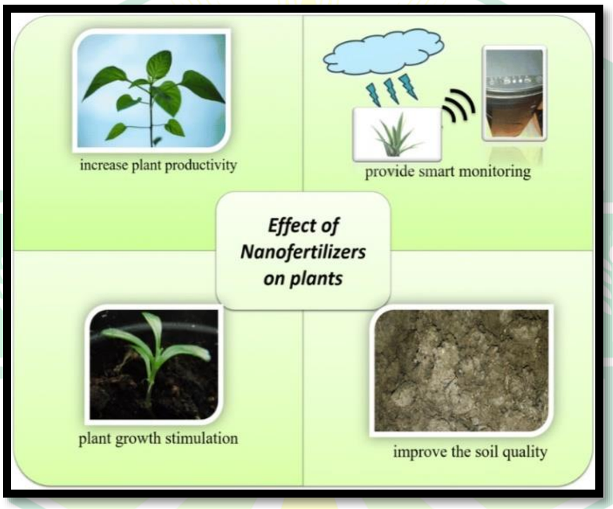
Smart Delivery System

Advancement in nanotechnology has improved ways for large-scale production of nanoparticles of physiologically important metals, which are now used to improve fertilizer formulations for increased uptake in plant cells and by minimizing nutrient loss.

Need of Nano fertilizers?

- After first green revolution, the agricultural production is experiencing a plateau now a days
- High ratio of NPK fertilizer *i.e.* 10: 2.7: 1
- Low output for per unit fertilizer used
- Increasing fertilizers requirement for producing more food grains to feed the burgeoning population of 1.4 billion in 2025.

Parameters	Chemical fertilizers	Nano – DAP fertilizer
Size	9,000-30,000 nm	1-100 nm
Native P Mobilisation	Insignificant contribution	Increase of up to 30%
P use efficiency	15-20%	58-65 %
Adsorption in soil	By Ca, Fe, and Al	No interference due to nano size and foliar application
Plant initiative	Less initiative by plant mobilises soil P	Increase in the plant activity due to triggering of enzymes
Impact on foreign exchange	Import of raw material resulting in the drain on foreign exchange and reduction in government revenue due to more subsidy	No requirement of subsidy and import of raw material
Requirement of product	Large	80-100 times less than that of chemical fertilizer
Stress tolerant	No effect	Ten times more stress tolerant than the chemical fertilizer
Cost	Subsidized by the government	No subsidy from the government still 2-4 times less costly than the chemical fertilizer
Soil health	No improvement or adverse impact	Sustain the soil health with the recommended dose of Nano-fertilizer



Conclusions:

Nano DAP is a nanotechnology based revolutionized Agri input which provides both nitrogen and phosphorus to the plants that reduces the burden on usage of conventional chemical fertilizers which are the major causes of deteriorating the soil health. In rice 100% NK +50%P+root dipping+2 foliar sprays of Nano DAP show significant results. In wheat 100 % NK+75 % P +2 foliar sprays of Nano P at tillering and PI proved to be effective.75% NPK along with one Nano N and one Nano DAP spray at 30 ad 45 DAS results in higher b:c ratio.

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"Residue to Resource: Pathways for Sustainable Agriculture in Balodabazar District"

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Introduction

The Green Revolution transformed India into a food-secure nation, significantly increasing cereal production. However, it also brought a new challenge—the management of crop residues. Chhattisgarh, often called the "Rice Bowl of Central India," relies heavily on rice-based agriculture for rural livelihoods, making residue management a critical issue. In Balodabazar district alone, rice occupies about **2 lakh hectares**, generating vast amounts of straw and stubble after harvest.

While mechanization, especially the use of combine harvesters, has made harvesting faster and more efficient, it has also left large quantities of loose straw in the fields. Managing these residues is a major challenge for small and marginal farmers, who constitute the majority of the district's farming community. Residues left in the field can delay land preparation for the next crop, while collecting, transporting, or processing them incurs additional costs. With the **window between rice harvest and sowing of rabi crops such as wheat, chickpea, mustard, and lentil only 10–15 days**, farmers often resort to burning as the quickest and cheapest option.

However, this short-term convenience comes at a significant environmental and agronomic cost. Burning residues releases approximately **1460 kg CO_2, 60 kg CO, and 19 kg of ash per tonne**, while depleting soil organic carbon, destroying beneficial microbes, and reducing nutrient availability. Over time, this practice contributes to declining soil health, lower water retention, and reduced crop productivity.

Balodabazar's cropping systems—**rice–wheat, rice–chickpea, rice–mustard, rice–lentil, and rice–summer rice**—cover a rabi crop area of approximately **33,000 hectares**. Proper management of residues in these systems can return thousands of tonnes of carbon and nutrients to the soil, enhance productivity, and reduce environmental pollution. Recognizing crop residues as a **valuable resource rather than waste** is therefore essential.

Sustainable residue management practices not only protect soil and the environment but also improve farmer incomes and productivity. Experiences and demonstrations conducted by **KVK Balodabazar** have shown that converting residues into usable resources can prevent burning, increase yields, and promote climate-smart agriculture in the district.

Why Do Farmers Burn Crop Residues?

Crop residue burning is a complex issue influenced by both technological and socio-economic factors. In the rice–wheat and rice–chickpea cropping systems dominant in Balodabazar district of Chhattisgarh, farmers often face multiple constraints that make residue burning an immediate, though harmful, choice.

1. **Time Constraint:** In intensive rice-based systems, farmers typically have only 10–20 days between paddy harvest and the sowing of the succeeding crop, such as wheat or chickpea. The short turnaround period leaves little time for residue decomposition or field preparation through conventional methods, pushing farmers toward quick disposal by burning.
2. **Lack of Suitable Machinery:** Access to Happy Seeder, Super Straw Management System (SMS), balers, or other residue management implements remains limited, particularly for small and marginal farmers. Custom hiring centers are few, and operational costs often discourage use.
3. **Declining Livestock Population:** Traditionally, rice straw was a valuable fodder source. However, the declining cattle population and preference for mechanized farming have reduced the local demand for straw, leaving residues unutilized.
4. **Economic Burden:** Collecting, transporting, or composting crop residues increases labour and fuel costs. Farmers perceive these as non-remunerative activities, especially in the absence of direct financial incentives.
5. **Low Awareness:** Many farmers underestimate the loss of nutrients and soil organic matter, as well as the environmental hazards associated with burning.

Environmental and Soil Health Impacts of Burning

Open-field burning of crop residues has emerged as a major environmental and soil health concern in rice-dominated regions of India, including the Balodabazar district of Chhattisgarh. The immediate convenience of burning residues conceals its far-reaching adverse effects on air quality, soil fertility, and ecosystem balance.

• **Air Pollution:** Burning releases large quantities of **carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and particulate matter**, which contribute to smog formation and respiratory disorders in humans and livestock. Seasonal burning events are increasingly linked to poor air quality even in semi-rural zones of central India.

• **Nutrient Losses:** A significant portion of essential nutrients is lost during burning—about **80% of nitrogen, 25% of phosphorus, 50% of sulphur, and 20% of potassium** present in residues. This deprives the soil of natural nutrient recycling and increases dependency on chemical fertilizers.

• **Soil Degradation:** The surface soil temperature can rise up to **43°C** in the top 2.5 cm during burning, destroying beneficial microorganisms, fungal spores, and soil enzymes like **urease, phosphatase, and dehydrogenase**, which are vital for nutrient mineralization and soil fertility.

• **Greenhouse Gas Emissions:** Burning of rice-wheat residues accounts for nearly **10% of India's total GHG emissions from agriculture**, aggravating climate change and undermining carbon sequestration efforts.

• **Biodiversity Loss:** Soil fauna such as earthworms, arthropods, and beneficial insects loses their habitat, leading to reduced soil aggregation and biological activity.

Sustainable Approaches to Crop Residue Management

Crop residue management plays a vital role in maintaining soil fertility, enhancing resource-use efficiency, and mitigating greenhouse gas emissions. In rice-based cropping systems of Balodabazar district, Chhattisgarh, sustainable alternatives to residue burning are crucial for conserving soil health and supporting climate-resilient agriculture. These approaches can be broadly categorized into in-situ and ex-situ management, complemented by modern mechanization and technological innovations.

1. In-situ Management

In-situ residue management focuses on retaining and utilizing crop residues within the field itself to enrich soil properties and improve the agro-ecosystem. These practices help conserve soil moisture, reduce nutrient losses, and foster biological activity.

• Mulching

Retaining crop residues as mulch on the soil surface helps in moisture conservation, weed suppression, and temperature regulation. In the dry and hot rabi season of Balodabazar, mulching significantly reduces irrigation requirements. Over time, decomposition of residues adds organic matter and nutrients to the soil, improving its structure and porosity.

• Conservation and Zero Tillage

Conservation tillage systems, such as zero tillage with residue retention, minimize soil disturbance while improving soil organic carbon, microbial biomass, and water infiltration. Long-term studies in the Chhattisgarh plains indicate that zero-till wheat after rice harvest enhances soil aggregation, root proliferation, and nutrient-use efficiency, leading to better yields with reduced fuel and labour costs.

• Happy Seeder Technology

The Happy Seeder is a revolutionary implement that enables direct sowing of wheat or chickpea into standing paddy stubbles without the need for residue burning or removal. It cuts and lifts the standing stubble, places seeds in the soil, and deposits straw mulch over the sown rows. Research has shown that Happy Seeder-based systems result in 29% higher nitrogen uptake, 37% higher crop yield, and 78% lower greenhouse gas emissions compared to conventional burning. In the context of Balodabazar, promoting Happy Seeder through custom hiring centres and farmer cooperatives can provide a scalable solution for small and marginal farmers.

• Straw Management System (SMS)

The Straw Management System (SMS), fitted to combine harvesters, uniformly chops and spreads the residue across the field, making it easier for subsequent incorporation or direct seeding operations. It prevents residue heaps and facilitates decomposition when integrated with microbial decomposers such as Pusa Decomposer or locally available lignocellulolytic fungi.

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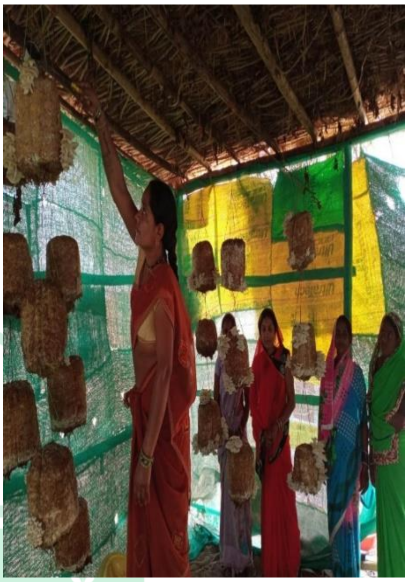
2. Ex-situ Management

When in-situ incorporation is not feasible due to labour or machinery constraints, ex-situ utilization of crop residues provides multiple opportunities for value addition and income diversification.

• Biochar Production

Thermal decomposition of crop residues under limited oxygen at 500–700°C produces biochar, a stable form of carbon that can be applied to soils. Biochar enhances soil fertility, cation exchange capacity, and water retention, while also acting as a long-term carbon sink. For regions like Balodabazar with declining organic carbon levels, biochar application can play a key role in soil rejuvenation.

• Mushroom Cultivation



Residues such as paddy and wheat straw serve as excellent substrates for mushroom cultivation. Approximately 1 tonne of straw can produce 50–100 kg of mushrooms, providing farmers with an additional source of income and nutrition. Training rural youth and women's self-help groups in mushroom production can create livelihood opportunities while reducing residue waste.

• Livestock Feed Enrichment

Although the demand for straw as fodder has declined due to mechanization, residues can still be nutritionally enriched through urea treatment or microbial inoculants to improve their digestibility. Such enriched fodder supports livestock rearing in mixed farming systems, ensuring resource recycling at the farm level.

3. Technological Innovations

Mechanization is a game-changer in residue management, offering practical and scalable solutions for farmers in Balodabazar. Various implements and technologies are available for residue handling, incorporation, and seeding:

	
Mulchers and Shredders: Efficiently chop residues into small pieces, facilitating decomposition and even spreading across the field.	Disc Harrows and Chisel Ploughs: Incorporate residues into the soil, enhancing organic matter integration and improving soil aeration.

	
Zero-Till Drills and Happy Seeder: Enable direct sowing of crops without removing residues, reducing time, labour, and fuel costs.	Super Straw Management System (SSMS): Improves straw distribution and ensures better seed–soil contact during sowing operations.

Happy Seeder-based systems have emerged as the most profitable and sustainable solution, increasing farmer income by 10–20% compared to residue burning while improving soil organic carbon, biological activity, and overall ecosystem health. Promoting these technologies through custom hiring centers, overnment subsidies, and skill training can accelerate adoption and make Chhattisgarh a model state for sustainable residue management.

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FROM FARM TO FORK: STATUS, CONSTRAINTS, AND SOLUTIONS IN VEGETABLE TRANSPORT

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Abstract

Efficient transportation plays a pivotal role in ensuring the availability, affordability, and quality of vegetables from farm to consumer. In India, a significant proportion of post-harvest losses, estimated between 12% and 20%, occur during transportation due to inadequate infrastructure, lack of cold chain facilities, and inefficient logistics systems. This study examined the present status, major issues, and emerging strategies for vegetable transportation. Conventional modes such as roads and rails continue to dominate, but government initiatives such as the Kisan Rail and Krishi UDAN schemes have expanded the market access for perishable produce. The adoption of sustainable and innovative technologies, including electric and biodiesel vehicles, autonomous trucks, drones, and controlled-atmosphere systems, has begun to redefine the efficiency and environmental sustainability of supply chains. In addition, advanced logistics software and IoT-based monitoring tools enhance real-time tracking, route optimization, and temperature control. Integrating these modern solutions with policy support and farmer participation can significantly reduce losses, improve profitability, and promote resilient low-carbon food transport systems.

Keywords: Vegetable transportation, post-harvest losses, cold chain logistics, Kisan Rail, Krishi UDAN, sustainable transport, autonomous vehicles, drones, refrigerated transport, controlled atmosphere systems, supply chain efficiency, India.

Transportation of vegetables

Transportation of vegetables refers to the movement of vegetables from one place to another, typically from where they are grown to where they are consumed. This process is crucial to ensure that fresh vegetables are available for sale and consumption. It primarily involves a chain of activities in the form of collection from farms, storage, and distribution to markets, retailers, and consumers.

Purpose of transportation

Transportation helps make vegetables more accessible. It is important to help them achieve food security characterized by a dependable and sustainable supply of quality produce at reasonable prices to communities. This then addresses a balanced diet, since vegetables help maintain good health and avoid nutritional deficiencies. Improved access and distribution systems will reduce losses, reduce food waste, and maximize available food supply.

Post harvest losses of vegetables in India

A study undertaken by NABCONS has estimated that the horticulture sector faces gigantic post-harvest losses, estimated to be in the range of 12% to 20% of the total production. A substantial portion of this wastage is said to take place during transportation, contributing to 5% to 10% of total losses.

The various modes of transport employed for vegetable crops include

- Road transport
- Rail transport
- Water transport
- Air transport

Factors to consider for the selection of mode of transportation

The efficiency of the movement of goods can be achieved by carefully considering various means of transportation based on some key aspects: the nature of the goods to be moved, the distance to cover, the availability of sufficient means of movement and the cost to incur, whether the means of transport conform to the relevant laws and international regulations governing such movements across borders, the sizes and lots to be moved, and finally, the prices of the product to be delivered so that the price is fairly competitive, with the inclusion of a transport cost element.

Sustainable transportation

Sustainable transportation in vegetable supply chains ensures a low environmental impact, while maintaining efficiency and cost-effectiveness.

- **Electric Vehicles:** Completely zero-emission vehicles run only on electricity, and thus reduce greenhouse gas emissions considerably. In addition to cleaner air while moving vegetables, EVs contribute to reducing the operating costs and maintenance expenses over time. The sustainability benefits of EVs are amplified when paired with renewable energy sources for charging.
- **Biodiesel or Alternative Fuel Vehicles:** These vehicles run on renewable fuels such as biodiesel, CNG, or hydrogen and depend less on the consumption of fossil fuels, thereby supplying a lower carbon footprint. Biodiesel is manufactured from vegetable oils or animal fats and can be utilized in existing diesel engines with little adaptation, making it both practical and scalable.
- **Rail transportation:** Rails are one of the most energy-efficient and environmentally friendly modes of land transportation, especially in long-distance hauls. It can move large volumes of vegetables simultaneously, reducing per-unit transportation emissions and relieving road congestion. Modern refrigerated railcars maintain the quality of fresh produce in transit, whereas their integration with intermodal logistics systems offers seamless connectivity to trucks for last-mile delivery.

Kisan Rail Service

Indian Railways run Kisan Rail train services to transport perishable agri-products, including milk, meat, and fish. The primary objective of running Kisan Rail trains is to increase income in the farm sector by connecting production centers to markets and consumption centers. Commodities covered perishables, including fruits, vegetables, meat, poultry, fisheries, and dairy products. Main crops/farm-produce transported via Kisan Rail train include oranges, onion, potato, banana, mango, tomato, pomegranate, custard apple, capsicum, chikoo, carrot, etc., Routes covered: 167 routes have been operationalised over 2300 services.

Salient features of kisan rail service

Kisan Rail is a multi-commodity, multi-consignor and consignee, multi-loading/unloading transportation product designed to provide wider market to the Kisan. The first Kisan Rail train was flagged off on 07.08.2020 between Devlali (Maharashtra) and Danapur (Bihar). Kisan Rail trains are run on time-tabled paths, and their punctuality is strictly monitored to avoid any en-route detentions/delays. The movement of perishables, including fruits, vegetables, meat, poultry, fishery, and dairy products, from production or surplus regions to consumption or deficient regions. There is no minimum limit on the quantity that can be booked; hence, even small and marginal farmers can reach larger and distant markets.

Transportation charges in Kisan Rail Service

Under "Operation Greens – TOP to Total" scheme of Ministry of Food Processing Industries a subsidy of 50% is being granted on the transportation of fruits and vegetables through Kisan Rail. This subsidy is granted upfront at the time of booking itself to consignors/farmers so that the benefit reaches the farmers without any hassles or procedural delays. In railways there are 4 types of parcel tariffs for transporting the commodities namely

Parcel tariff	Transportation charges in Rs for 1 to 10 Kg (1-5 Km)
Luggage scale	7.53
Rajdhani scale	6.28
Premier scale	**4.19**
Standard scale	2.10

Commodities booked through Kisan Rail trains are charged at ‘P’-scale of parcel tariff.

Krishi Udan Scheme

Krishi UDAN Scheme was launched in August 2020, on international and national routes to assist farmers in transporting agricultural products so that it improves their value realization. Ensure seamless, cost-effective, time-bound air transportation and associated logistics for all Agri-produce originating especially from Northeast, hilly and tribal regions of the country. The enhanced version of the Krishi UDAN scheme was formulated with support from AAI Cargo Logistics and Allied Services Company Limited (AAICLAS) - a 100% subsidiary of the Airports Authority of India and Invest India, India's national Investment Promotion & Facilitation Agency, under the Ministry of Commerce and Industry.

Objectives of Krishi Udan Scheme

To increase the share of air in the modal mix for transportation of Agri-produce that includes horticulture, fishery, livestock & processed products. To achieve better convergence on various components catering to the development of sustainable and resilient Agri-produce value chains across various schemes of the Central and State Governments and their associated agencies as well as the resources committed by the private sector to improve supply chain competitiveness by providing more air connectivity (national and international) between origin-destination airports aimed at bringing in improved logistics efficiency.

Improvement in infrastructure and performance in processing of air cargo by all stakeholders, including Agri-produce, horticulture, fisheries, livestock products at airports and off-airport facilities by regulatory participating governmental agencies (PGAs). Imparting special focus to air freight of organic and natural produce of NER, Tribal and Hilly Districts. Achieving better and timely mapping of Agri-produce production/ supply centers with domestic demand clusters and international markets in sync with the marketing strategies. Promoting adoption of plant quarantine and other regulatory requirements (at airport) in the export supply chains end-to-end. Enabling paperless and contactless interface with all stakeholders through digitization and digitalization via integration with existing e-platforms and their creation as required.

7 focus routes & products

Routes	Products
Amritsar – Dubai	Babycorn
Darbhanga - Rest of India	Litchi
Sikkim - Rest of India	Organic produce
Chennai, Vizag, Kolkata - Far East	Seafood
Agartala - Delhi & Dubai	Pineapple
Dibrugarh – Delhi & Dubai	Mandarin & Oranges
Guwahati - Hong Kong	Pulses, fruits & vegetables

INNOVATIVE TRANSPORTATION METHODS

Hyperloop technology

Hyperloop is the high-speed transportation system where cargo pods travel through low-pressure tubes. The hyperloop might solve logistics challenges that include shorter order delivery times or pollution caused by freight haulage. The loads would be placed in capsules that would travel through a tunnel at about 750 mph. With Hyperloop technology, a low-energy cost alternative could be established for long-distance journeys by trucks, freight trains, or airplanes.

This setup contains a capsule that levitates using magnetic levitation. The propulsion, via an electric motor, enables this mode of transportation to travel at very high speeds owing to the absence of friction and the virtual absence of air resistance. More importantly, it will be able to do so at relatively low levels of energy consumption. For perishable goods transport, it can be fitted with temperature-controlled pods for fresh produce.

Autonomous trucks

Autonomous trucks, or self-driving trucks, are increasingly explored in the perspective of an innovative solution that could help transport vegetables efficiently and sustainably. By integrating advanced sensors, AI-based navigation systems, and real-time route optimization, these vehicles provide considerable advantages in terms of logistics efficiency, reduced labor costs, and decreasing reliance on human drivers. Autonomous trucks can be set up with refrigeration or controlled atmosphere (CA) units to preserve the freshness of vegetables in transit and are thus highly effective in ensuring their quality while streamlining supply chains.

Autonomous vegetable transport systems are of great importance in managing all processes, both from farm to warehouse and inside the warehouse. They can load and unload vegetables directly from the fields or storage areas with minimal human effort at the farm-to-warehouse stage. Advanced route optimization technology will determine the most efficient delivery routes, saving time and fuel. In addition, their ability to work 24/7 can minimize total downtime during the transport process. From within the warehouse, autonomous vegetable transports enhance efficiency by moving vegetables internally to facilitate efficient storage and distribution processes. They undertake material processing tasks regarding the palletization and loading of goods to be transported in transport vehicles. They replace most of the labour-intensive processes, hence improving productivity by reducing labor costs while handling goods with consistency and at high speed.

Advantages and potential challenges

They offer higher efficiency, operating faster and more effectively compared to human-driven trucks, which will reduce delivery time and transportation costs. Additionally, these vehicles lower labour costs due to the reduced need for human drivers, thereby improving profitability. The key benefits include safety, whereby the autonomous systems minimize accidents and injuries associated with truck driving. Moreover, faster transport helps to retain freshness longer, reducing spoilage and assuring high-quality produce upon arrival.

However, in the case of autonomous trucks, these come with notable challenges: they need well-maintained roads and reliable communication systems, which may not be available across all regions. Besides that, the legislative and regulatory environment for autonomous trucking is also evolving and may create certain barriers to deployment. In addition, cost remains a barrier. Currently, an autonomous truck costs more than a traditional one, and this might push the adoption curve for such technologies until further technological advances and greater scale have lowered their price.

Electric Uncrewed Transport Vehicles (E-UTVs)

E-UTVs present an efficient solution for vegetable transport in greenhouses and farms. These vehicles feature autonomous navigation by the use of SLAM, LiDAR, and inertial systems for smart path planning. In addition, they have freshness preservation options for vegetables, such as refrigeration or CA systems. They can be fitted with automated handling mechanisms to load and unload the produce efficiently, minimizing labor and the possibility of damage. They are appropriate for greenhouse crops like tomato and pepper and even for farm-to-market transport on tricycle-like cargo models.

Drones for transporting vegetables

A pilot undertaken by MANAGE showed a 20% reduction in wastage with the use of drones to carry fresh produce. By reducing dependence on roadways, drone delivery helped to lower carbon emissions and helped in environmental sustainability in agriculture. According to Ankit Kumar, Founder and CEO of Skye Air Mobility, drone transport in the fruits and vegetables sector offers many benefits: cost savings, time savings, and reduced carbon footprint. These translate into more profit for the farmer, quicker delivery of fresh produce, and a more sustainable agricultural supply chain.

Disadvantages of using drones

Some of the key constraints include limited capacity, since a drone can carry very minimal loads compared to other means of transport. It is also weather-dependent, meaning heavy rain, strong winds, or fog could either delay or cancel the flight. Limited range and battery life restrict their operational distance; recharging or changing the batteries often becomes necessary.

The very high cost of purchase, operation, and maintenance is out of reach for many, especially small-scale farmers. Adding to these are infrastructure limitations, such as the general lack of landing zones or charging stations in rural areas. Safety and security risks include mid-air collisions, technical malfunctioning, and even the possibility of theft and misuse.

Other challenges include noise and privacy, which may arise and lead to community resistance, and regulatory barriers due to changing aviation legislation and flight restrictions. Finally, the quality of the product is compromised in case of damage during flight, takeoff, or landing, especially on fragile fruits and vegetables.

REFRIGERATED TRANSPORT

Reefer Trucks or Refrigerated boxcars

Effective cold chain management of perishable cargo requires a combination of precise practices and advanced technology: preserving products' freshness by maintaining the right temperature, ensuring proper airflow inside the vehicle to avoid uneven cooling of goods, good insulation, and using a reliable refrigeration system that maintains temperatures between -1°C and 13°C (30°F to 55°F) during transportation. Several products can be stored at their ideal conditions within the same insulated vehicle but in different temperature compartments.

Continuous monitoring of temperature and performance allows for early detection of issues; maintenance ensures hygiene and prevention of contamination. Integrating modern technologies such as GPS and telematics allows for route efficiency, location tracking, and monitoring of vehicles in real-time concerning cold chain integrity.

Major CA transportation systems in transportation

Oxytral system

The Oxytral system is one of the most used technologies for the creation of a controlled atmosphere applied in sea transportation. This system uses the generation of nitrogen and carbon dioxide scrubbing to maintain consistent atmospheric conditions within shipping containers or cargo holds. The Oxytral system continuously monitors and adjusts gas levels using sophisticated sensors and automated controls.

The particularly effective aspect of the Oxytral system is its ability to create a nitrogen-rich atmosphere; it separates nitrogen from ambient air through membrane technology. This reduces oxygen levels down to the desired range, usually within 1-5%, depending on the produce. Excess carbon dioxide is removed with the use of special scrubbers. The system is particularly used for the transportation of apples, pears, and stone fruits across oceanic routes.

Tectrol system

This system uses a combination of low oxygen and high carbon dioxide levels in concert with close temperature and humidity control. Helps to maintain the quality and freshness of the produce by reducing the potential of microbial growth and moisture loss. Utilized in the transportation of berries, grapes, and other delicate fruits.

One of the major beneficial features of the Tectrol system is its capability to adapt to a wide range of load sizes and types of mixed cargo. The possibility of maintaining different atmospheric zones within the same transport unit enables the simultaneous transportation of produce types that have various CA requirements.

CONAIR-Plus system

The CONAIR-Plus is designed to handle perishable commodities such as fruits, vegetables, and flowers intended for transportation. The system combines a controlled atmosphere with refrigeration in order to create an optimum storage environment. The system helps in maintaining the quality and shelf life of the produce by regulating the levels of oxygen, carbon dioxide, and ethylene, besides controlling temperature and humidity.

The presence of IoT integrations in monitoring and real-time adjustments during transport sets the CONAIR-Plus system apart. Logistics managers will track atmospheric conditions, temperature, and produce quality indicators from anywhere in the world to make immediate adjustments if conditions drift out of optimal ranges. This system proves to be most effective for high-value produce where quality premiums justify the added investment in the technology.

Logistics software

Modern logistics in the transportation of vegetables is characterized by several advanced features that enhance efficiency, quality, and cost-effectiveness. Real-time tracking will permit continuous monitoring of each shipment for visibility and safety during the entire journey. Route optimization utilizes GPS and data analytics to determine the quickest and most fuel-efficient pathways, reducing transit times while minimizing spoilage risks.

Temperature control systems maintain ideal storage conditions, preserving freshness and extending shelf life. Digital documentation streamlines paperwork, making record-keeping faster, more accurate, and easily accessible. Freight cost management tools track expenses, identify opportunities to save and improve budget control. Besides, faultless integration with WMS guarantees trouble-free coordination of transport and storage operations and enhances supply chain performance on the whole.

Specific examples of logistics software

TMS is essential in streamlining all attributes of the transportation process: from planning and execution to real-time tracking. It thus helps a logistics manager to effectively schedule shipments, uses available resources in an appropriate manner, and monitors the same to ensure timely deliveries. As the TMS integrates with other supply chain tools, coordination between different participants in the transport value chain improves, operational bottlenecks decrease, and general transport efficiency increases.

Cold Chain Logistics solutions play a crucial role in the transportation of perishable items such as vegetables, which demand specified, unaltered low-temperature conditions throughout the process to retain freshness. Specialized software keeps track of temperature conditions in real-time, recognizes deviations immediately, and sends alerts to avoid spoilage. These solutions also help optimize storage environments, document compliance with food safety regulations, and minimize losses resulting from temperature mishandling. Fleet management software offers total control over the vehicles used in vegetable transportation, enabling their top performance and cost efficiency. Monitoring fuel consumption, driver behavior, and preventive maintenance dates, this software minimizes vehicle downtime, extends vehicle life, and reduces operation costs. This also enhances the reliability of the delivery because the vehicles will be in their best state to support a smooth, efficient, and sustainable transportation process.

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Biotechnological approaches for enhancing salinity tolerance in rice

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Abstract

Salinity is a significant environmental stress that impacts rice production worldwide. Severe salt stress leads to osmotic imbalance, ion toxicity and oxidative damage resulting in poor growth and substantial yield losses. Hence development of salt-tolerant rice varieties through advanced biotechnological tools remains a feasible and cost-effective solution. However, due to the complex mechanisms of salinity tolerance, which involves multiple physiological and molecular pathways both traditional breeding methods and modern genetic engineering techniques have been used to enhance salinity tolerance in rice. Conventional breeding allows selection and introgression of salt-tolerant traits based on plant phenotypes. Marker-assisted selection further speedup the breeding process by enabling early and accurate identification of desirable traits. Modern genetic engineering allows introduction of salt-tolerance genes associated with ion regulation, osmotic adjustment, and antioxidant defense into susceptible cultivars through transgenic technology. An integrated approach combines two or more of the above approaches for developing high-yielding, salt-tolerant rice cultivars. By improving the genetic potential for salinity resistance, we can develop rice varieties that thrive in saline-prone environments, thereby contributing to global food security in regions affected by soil salinization.

Key words: Rice, Salinity tolerance, Conventional breeding and Advanced breeding techniques.

Introduction:

Rice (*Oryza sativa*) is one of the most important staple crops worldwide, providing food and income to millions. However, its productivity is significantly impacted by abiotic stresses, with salinity being a major concern that can severely hinder both growth and yield. As climate change exacerbates environmental challenges, salinity continues to pose a pressing issue for rice cultivation, particularly in coastal and irrigated areas. Soil salinity causes osmotic stress, ion toxicity, and nutrient imbalances, which lead to stunted growth, reduced photosynthesis, and ultimately lower crop yields. In response to this challenge, scientists and agricultural researchers are increasingly focused on developing rice varieties that can tolerate salinity. While traditional breeding methods have contributed to some improvements, the complexity of salinity tolerance encompassing multiple physiological and molecular mechanisms has made progress slow and labor-intensive. Recent advancements in genetic engineering and molecular breeding techniques have opened new avenues for accelerating the development of rice varieties that can withstand high salt concentrations. This article discusses the current strategies employed in genetic engineering and breeding to enhance salinity tolerance in rice. It highlights key genetic loci associated with salt tolerance, identifies molecular markers for selective breeding, and explores the latest innovations in transgenic approaches. By integrating traditional breeding methods with cutting-edge biotechnological tools, researchers are paving the way for developing rice varieties that can thrive in saline environments, ensuring food security and enhancing the resilience of global rice production systems.

1. Conventional Breeding Approaches for Salinity Tolerance

Conventional breeding has been a foundational method for enhancing salinity tolerance in rice. This process involves selecting natural variations in salt tolerance found within rice populations and crossbreeding them to create improved varieties. Although traditional breeding is effective, it can be a slow and challenging process due to the polygenic nature of salinity tolerance, which involves multiple genes.

Selection and introgression from Salt-Tolerant Germplasm:

- The first step in traditional breeding for salt tolerance involves identifying rice varieties or wild relatives that naturally exhibit salt tolerance. These varieties are then used as parents in breeding programs.

- ***Oryza sativa*** (cultivated rice) and ***Oryza barthii*** (African rice), among other wild species, have been used to develop salt-tolerant cultivars.
- **Screening for Salt-Tolerant Traits**: Rice lines are screened for salt tolerance at various developmental stages (seedling, vegetative, reproductive). Traits such as root length, shoot growth, sodium exclusion ability, and maintenance of K^+/Na^+ homeostasis are often used as markers for salinity tolerance.
- **Crossbreeding and Hybridization**: Crossbreeding involves crossing salt-tolerant varieties with high-yielding but salt-sensitive varieties to combine the best traits of both.
- **Backcross Breeding**: This is used to introgress the salinity-tolerant genes from wild relatives into elite rice cultivars. By backcrossing salt-tolerant traits over several generations, breeders can develop cultivars with both high productivity and improved salt tolerance.

QTL Mapping and Marker-Assisted Selection (MAS):

- **Quantitative Trait Loci (QTL) Mapping** has been used to identify regions of the genome associated with salt tolerance. For example, genes related to ion transport (e.g., *SOS1*, *HKT1*), osmotic adjustment (e.g., *P5CS*), and antioxidant defense (e.g., *SOD*, *APX*) have been mapped to specific regions in the rice genome.
- **Marker-Assisted Selection**: Once QTLs linked to salt tolerance are identified, molecular markers are used to select individuals with these traits more efficiently. These speeds up the breeding process by reducing the need for field testing, thus accelerating the development of salt-tolerant rice cultivars.

2. Genetic Engineering for Salinity Tolerance in Rice

Genetic engineering, also known as transgenic technology, provides a more direct method for introducing specific salt tolerance traits into rice. By isolating and inserting genes that confer resistance to salinity, this technique can enhance rice's ability to withstand salt stress more effectively and efficiently than traditional breeding methods.

Genes for Sodium and Ion Transport:

- ***SOS1* (*Salt Overly Sensitive 1*):** The *SOS1* gene encodes a Na^+/H^+ antiporter that is responsible for pumping excess sodium out of plant cells. Over expressing *SOS1* in rice has been shown to enhance salt tolerance by reducing sodium accumulation in leaf tissues, thereby preventing toxic effects.
- ***HKT1* (*High-Affinity Potassium Transporter 1*):** This gene regulates the selective uptake of sodium and potassium ions. Engineering rice to express *HKT1* from salt-tolerant species, such as *Aeluropus littoralis*, can improve sodium exclusion and enhance salt tolerance.

Genes for Osmotic Adjustment:

- ***P5CS* (*1-pyrroline-5-carboxylate synthetase*):** P5CS is an enzyme that plays a crucial role in the biosynthesis of proline, an important compatible solute that aids in osmotic adjustment. When *P5CS* is overexpressed, it leads to increased proline accumulation, which helps rice plants better cope with osmotic stress caused by salinity.
- ***TPS* (*Trehalose-6-phosphate Synthase*):** Trehalose is a sugar that serves as a compatible solute, stabilizing cellular structures during stress. Genetic engineering of rice to over express *TPS* improves tolerance to salt and drought by enhancing osmotic regulation.

Antioxidant Defense and Stress Tolerance:

- ***Superoxide Dismutase* (*SOD*):** SOD enzymes play a crucial role in scavenging reactive oxygen species (ROS) that are generated during salinity stress. Engineering rice to overexpress *SOD* can enhance the plant's ability to neutralize oxidative damage caused by high salinity.
- ***Catalase* (*CAT*) and *Peroxidase* (*POX*):** These enzymes are also vital components of the antioxidant defense system. Transgenic rice that expresses *CAT* or *POX* genes demonstrates improved tolerance to salt stress by reducing ROS accumulation.
- ***OsDREB* (*Dehydration-Responsive Element Binding*):** Over expressing *OsDREB1* in rice enhances the expression of genes related to stress responses, which include mechanisms for osmotic adjustment and antioxidant defense. This improvement contributes to better salinity tolerance in the plants.

Regulation of Hormonal Pathways:

- **Abscisic Acid (ABA)**: ABA is a key hormone involved in salt stress responses, regulating processes like stomatal closure and gene expression. Engineering ABA biosynthesis or signaling can enhance salt tolerance.

- **Cytokinins and Auxins**: Manipulating the balance of plant hormones like cytokinins and auxins can help modulate growth and development under salinity stress.

3. Challenges and Future Directions

While genetic engineering offers a powerful means to enhance salinity tolerance in rice, several challenges still need to be addressed:

Regulatory and Public Acceptance: The use of genetically modified (GM) crops encounters regulatory obstacles and public skepticism, especially in certain regions. It is essential to ensure the safety, efficacy, and acceptance of transgenic rice varieties for their widespread adoption.

Gene Complexity and Trade-offs: Salinity tolerance is a polygenic trait, meaning it involves the interaction of multiple genes. When engineering rice for salt tolerance, it is important to consider potential trade-offs, such as reduced growth or yield in non-stressed conditions. Successfully balancing salt tolerance with high productivity is crucial for the viability of GM rice varieties.

Environment-Specific Adaptations: Salinity tolerance is highly influenced by environmental factors, such as soil type, salinity levels, and climate conditions. Tailoring salt-tolerant rice varieties to specific environments requires careful selection of genes and testing across different saline conditions.

Gene Stacking: One promising strategy to enhance salinity tolerance is gene stacking, which involves introducing multiple salt-tolerant genes into a single rice cultivar.

4. Integrated Approaches: Combining Genetic Engineering and Conventional Breeding

An integrated approach that combines genetic engineering with conventional breeding is considered the most promising strategy for improving salinity tolerance in rice.

- **Marker-assisted selection (MAS)** can be used to identify and select rice plants that carry the desired transgenic traits or salt-tolerant alleles without relying on phenotypic screening. Use of markers speeds up the selection process and reduces breeding cycles when compared to the conventional methods. Marker-assisted gene stackingfacilitates the simultaneous incorporation of multiple stress-tolerance traits, such as ion transport, osmotic adjustment, and oxidative stress defense, into a single cultivar to generate synergistic effect that amplify overall salinity tolerance.
- **Backcross Breeding with Transgenic Traits**: Transgenic rice varieties with salt tolerance genes can be backcrossed with elite, high-yielding rice cultivars to combine salt tolerance with superior agronomic traits such as high yield, good grain quality and disease resistance.
- **Gene Editing**: **CRISPR/Cas9** technology offers the potential for precise editing of of salt tolerance-related genes (*OsHKT1*, *OsRR22*) and transcription factors (*OsDREB1*, *OsNAC*) to enhance salt tolerance without introducing foreign genes. The genome-edited salt tolerant alleles can be combinedwith MAS to develop non-GM version of genome-edited rice with improved salinity tolerance and high yield.

Conclusion:

The development of salt-tolerant rice is crucial to meeting the increasing global demand for food, especially as saline soils continue to expand due to climate change. Researchers are making significant progress in creating rice varieties that can thrive in salty environments by combining traditional breeding methods with advanced molecular tools. These tools include marker-assisted selection, genetic engineering, and gene editing. As these strategies evolve, they offer hope for a more resilient and sustainable future for rice production, ultimately contributing to global food security in the face of rising salinity.

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IDEOTYPE CONCEPT IN CROPS

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Introduction:

An ideotype is a conceptual model of an ideal plant type possessing morphological and physiological traits that enable maximum yield of a crop variety within a specific set of environmental conditions. The concept of crop ideotype was first proposed by the renowned plant breeder, Donald in 1968. Ideotype breeding is a strategic approach to crop improvement that involves designing a theoretical plant model with the best combination of morphological, physiological and genetic traits to enhance yield potential under particular environment. Plant breeders develop hypothetical plant types to achieve specific objectives such as increased yield potential, improved quality and enhanced resistance to pests and diseases. Breeders focus on identifying and selecting specific traits that are critical for crop performance, enabling the development of new varieties that are more productive, resilient and adaptable to changing environmental conditions.

Crop ideotype

A crop ideotype is a biological model of a plant which can theoretically achieve maximum yield potential and superior quality within a defined environment. It is expected to yield higher quantity and quality of economic products such as grain, fibre or oil, when developed and released as a cultivar. Ideotype is also referred to as an ideal plant type or model plant type representing a conceptual design of a plant with optimal traits for high productivity within a defined environment.

Objectives of the ideotype concept in crop plants

1. To develop an ideal plant type with a desirable combination of traits for maximum yield potential.
2. To integrate physiological, morphological and genetic traits for holistic crop improvement.
3. To develop crop varieties suited to specific environments or production systems.
4. To improve resistance to major biotic and abiotic stresses (pests, diseases, drought etc.).
5. To enhance resource-use efficiency.

Ideotype of crop plants

1. Wheat (*Triticum aestivum* L.) Ideotype

Donald (1968) proposed the concept of an ideotype in wheat. The ideotype for the wheat crop is described as follows:

1. Short strong stem
2. Relatively shorter height (80-90 cm)
3. Erect and few small leaves
4. Moderate tillering (9-10)
5. Strong and deep root system
6. More number of fertile florets per unit area
7. Days to heading (70 days)
8. Days to maturity (125-135)
9. Larger and erect ear
10. Presence of awns
11. Single culm
12. Photoperiod insensitivity
13. Proper partitioning and translocation of assimilates

14. Rust resistance
15. 1000-grain weight (>45 g)
16. High harvest index (>50%)

2. Rice (*Oryza sativa* L.) Ideotype

Jennings (1964) proposed the ideotype concept in rice. He suggested that the ideal or model plant type in rice consists of the following characteristics:

1. Semi-dwarf stature (<110 cm)
2. Short, erect, thick and highly angled leaves
3. Effective rooting, strong and deep root system
4. High tillering capacity
5. Greater culm diameter and culm strength
6. Lower relative internodes elongation
7. Synchronized flowering
8. Large panicles
9. More panicles per m^2
10. More grains per panicle
11. Days to Maturity (100-130 days)
12. High harvest index (>55%)
13. Moderate seed dormancy

New plant type of rice

The International Rice Research Institute (IRRI) proposed ideotype concept for the New Plant Type (NPT) of rice in 1989, which comprised the following desirable morphological and physiological features:

1. Reduced tillering (9-10 tillers per plant in transplanted conditions)
2. No unproductive tillers
3. Leaves are dark green, thick and erect
4. Root system is vigorous and deep
5. Higher grains per panicle (200-250 grains)

3. Super hybrid rice

The ideal plant type of super hydrid rice consist of following features:

1. Reduced plant height (90-100 cm)
2. Moderate tillering capacity (8-12 tillers $plant^{-1}$)
3. Leaves thick, erect, narrow and V-shaped for efficient light use and photosynthesis
4. Maximum harvest index (0.55)
5. More number of panicles per m^2 (270-300)

4. Maize (*Zea mays* L.) Ideotype

Mock and Pearce (1975) proposed ideal plant type of maize. In Maize, higher yields were obtained from the plants consisting of following features:

1. Early maturity
2. Plant height (150-180 cm)
3. Stronger and deep root system
4. Stiff- vertically oriented leaves above the ear
5. Small tassel size
6. Low number of tillers
7. Large cobs
8. Angled leaves for better light interception
9. Maximum photosynthetic efficiency
10. High radiation use efficiency
11. Maximum translocation of photosynthate from source to sink
12. Short interval between pollen shedding and silk emergence
13. Photoperiod insensitivity

14. Cold tolerance of germinating seeds and developing seedlings.
15. Maximised grain-filling period
16. Slow leaf senescence

5. Sorghum (*Sorghum bicolor*) and Pearl millet (*Pennisetum glaucum*) Ideotype

Swaminathan (1972) proposed an ideal plant type for sorghum and pearl millet, higher yield can be obtained from following features:

1. Semi-dwarf plant height for lodging resistance
2. Enhanced canopy photosynthetic efficiency and radiation use efficiency
3. Reduced photorespiratory losses and efficient carbon fixation
4. Optimized canopy structure for sustained CO_2 fixation and light interception
5. Photoperiod and temperature insensitivity for wide adaptability
6. High nutrient use efficiency and responsiveness to fertilization
7. High photosynthetic ability
8. High water use efficiency (WUE)
9. Resistance to biotic and abiotic factors
10. Higher harvest index
11. Suitability to mechanical harvesting

6. Barley (*Hordeum vulgar* L.) Ideotype

Rasmusson (1987) proposed an ideal plant type of six rowed barley. He proposed ideotype of barley with following main features:

1. Short stature
2. Strong stem with few erect leaves
3. A single culm
4. Elongated awns
5. Maximum harvest index
6. Enhanced total biomass production
7. Increased kernel weight
8. Higher of number of kernels

7. Cotton (*Gossypium hirsutum* L.) Ideotype

Singh and Narayanan (1993) proposed ideal plant type of cotton under rainfed conditions. He proposed ideotype of cotton, higher yield can be obtained from following features:

1. Short stature (90-120 cm)
2. Early maturity (150-165 days)
3. Fewer small and thick leaves
4. Compact and shorter stature
5. Indeterminate fruiting habit
6. Sparse hairiness
7. High nutrient-responsive
8. Medium-big size boll
9. Synchronous Bolling
10. Resistance to biotic and abiotic stress

Ideotype of Cotton under irrigated cultivation

1. Short stature (90-120 cm)
2. Short duration (150-165 days)
3. Compact and sympodial plant habit making pyramidal shape
4. Highly resistant to insect pests and diseases
5. Responsive to high fertilizer dose
6. High physiological efficiency
7. Higher degree of inter plant competitive ability
8. Determinate fruiting habit with unimodal distribution of bolling, suitable for mechanization

8. Chickpea (*Cicer arietinum* L.) Ideotype

Pande and Saxena (1973) proposed the ideal plant type of gram. They aimed to define a chickpea plant type suitable for rainfed conditions with the following features:

Rainfed condition

1. Early vigour
2. Modearte plant height (50-60 cm)
3. Tall, erect or semi erect plant
4. Deep taproot with good laterals
5. 9-10 well developed secondary branches
6. Early days to flowering (35-40 DAS)
7. Longer pods of 2-3 in the leaf axis and 2-3 seeds in each pod
8. Maximum pods per plant (60-80 pods plant^{-1})
9. Podding from 10th node upward
10. High harvest index (0.40-0.45)

Irrigated condition

1. High input responsiveness
2. Tall plant height (75-90 cm) and erect habit
3. Determinate growth and delayed senescence
4. Synchronous flowering
5. Short inter nodes and long fruiting branches
6. Lodging resistance
7. Pod bearing from 20 cm above the ground

9. Pigeonpea (*Cajanus cajan*) Ideotype

1. Semi-dwarf plant type (150-180 cm)
2. Deep and extensive taproot system
3. Active root nodules for a long time
4. Strong, sturdy stem to resist lodging
5. Determinate growth habit
6. Early vigour and canopy development
7. Moderately open canopy
8. Erect and compact branching habit
9. Middle and top bearing
10. Long floral axis having 2-3 flowers in each trifoliate axis.
11. Long fruiting branches for high yield
12. Non-cluster pod bearing
13. Long pods containing 4-5 bold seeds
14. Short to medium-duration (120–160 days)
15. Synchronous flowering and pod setting
16. High harvest index (40-45%)
17. Resistance to major pests and diseases
18. Spreading type for intercropping in South and Central India
19. Compact plant type for intercropping in Northern India

10. Mungbean (*Vigna radiata*) Ideotype

Summer season

1. High initial growth vigour
2. Medium plant height (60-80 cm)
3. Short duration (50-60 days)
4. Determinate growth habit
5. Synchronous flowering and maturity
6. More number of pods at top of the plant

7. Non-shattering habit
8. Longer pods (7-10 cm) with more than 10 seeds pod^{-1}
9. Tolerance to terminal heat stress

Kharif season

1. Tall plants (80-100 cm) with more branches
2. Optimum duration (65-75 days)
3. Balanced vegetative growth
4. Clear distinction between vegetative and reproductive phase
5. Synchronous maturity
6. More number of clusters per plant and pods per cluster
7. More number of seeds pod^{-1}
8. Shattering and pre- harvest sprouting tolerance

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THE ROLE OF LYOPHILIZATION IN MODERN FOOD PRESERVATION: TECHNIQUES AND BENEFITS

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ABSTRACT

Freeze drying is a low temperature dehydration process in which frozen food is subjected to vacuum, allowing ice to sublime directly into vapour. This method preserves cellular structure, minimize shrinkage, and retains heat sensitive compounds, yielding products of superior nutritional and sensory quality. Freeze drying maintains colour, flavour, aroma and bioactive compounds, while producing lightweight foods with excellent rehydration properties. It is widely applied to fruits, vegetables, dairy products, instant coffee and tea, meats and nutraceuticals. This technology is highly advantageous for heat sensitive and high value foods, though it requires long processing times and significant energy, restricting its use mainly in premium markets. Advances in equipment design and hybrid drying technologies are improving efficiency, while consumer demand for minimally processed, natural foods continue to drive market expansion. Overall, freeze-drying remains a critical preservation method in the food industry, offering unmatched product quality and functionality despite cost and scalability challenges.

Key words: Lyophilization, vacuum, high value food, heat sensitive, technology

INTRODUCTION

Freeze-drying, or lyophilization, is a dehydration method in which food is frozen and then placed under vacuum so that ice sublimates directly to vapour. The product is chilled below the triple point and pressure is reduced, causing ice to vaporize without passing through liquid. By operating at low temperature (typically below -40 °C), freeze-drying avoids the liquid phase, which minimizes structural collapse and pressure volatile and heat sensitive compounds.

Figure 1: Freeze dryer

In food industry, freeze drying is used for producing superior quality dried food products. The solid-state drying protects cellular structure and yields minimal volume loss. Consequently, fruits, vegetables, meats, coffee and even pharmaceuticals are often freeze-dried to extend shelf life while retaining colour, flavour and nutrients. Freeze dried foods can rehydrate nearly to original form, therefore they are used in instant meals, snacks, and astronaut or military rations. NASA's space and military food supplies have long relied on freeze-drying due to its stability and convenience. Demand is growing for freeze-dried products in organic, natural-food, and nutraceutical markets as consumer seek minimally processed high quality foods.

In contrast to hot-air or spray drying use high temperature that can degrade quality. Spray drying for example, atomize a liquid feed into a heated chamber (often 150-200°C). This is fast and inexpensive but can oxidize or denature flavour, colours and nutrients. By comparison, freeze-drying is essentially non-destructive: the process removes water without boiling or high heat, so the taste, aroma and nutritional content remain essentially unchanged. However, freeze drying typically consumes 4-10 times more energy than hot-air drying and requires long processing cycles. Thus, freeze-drying is often reserved for premium or heat sensitive foods, while bulk products (e.g. grains, cereals) use conventional drying.

PRINCIPLES OF FREEZE DRYING

Freeze-drying exploits the water phase diagram. By freezing the the food below 0°C and then reducing chamber pressure below the triple point of water (611 Pa at 0.001 0°C), ice can sublime directly to vapour. In practice, freeze drying starts at atmospheric conditions (point A on the diagram) and proceeds along the sublimation path to low pressure (point B). The phase diagram illustrates that at low pressure and temperature the liquid phase is bypassed.

There are three stages of freeze drying-

1. **Freezing:** The product is pre-frozen (often to -40°C to -50°C) so that all water is solid. Rapid or slow cooling may be used depending on the material. Slower freezing produces larger ice crystals (making sublimation easier), while rapid freezing yields finer crystals (better for preserving delicate structure). In all cases, freezing must reach well below the eutectic/triple-point temperature to avoid melting in later steps.
2. **Primary drying(sublimation):** Chamber pressure is lowered (to ~100–300 mTorr or 0.013–0.040 kPa) and controlled heat is supplied to the frozen product.Under these conditions, ice sublimes and about 95% of water is removed in this phase.The energy (latent heat of sublimstion, ≈619 cal/g) is delivered mainly through temperature-controlled shelves or by radiant heaters. A refrigerated condenser(typically -60 °C or colder) traps the water vapour as ice, protecting vaccum pump.
3. **Secondary drying(desorption):** After free ice is gone, bound water molecules remain in the product matrix.Shelf temperature is then raised (often 20-40 °C) while maintaining vaccum; this removes the chemically bound water by desorption. Secondary drying comtinues until residual moisture is typically <1-5%. The result is porous,dry matrix that rehydrates quickly.

Throughout these stages pressure and temperature is controlled carefully. Freezing takes place at an atmospheric pressure, but primary and secondary drying occur under high vacuum (to facilitate sublimation). The process hinges on remaining below the triple point throughout drying. If temperature or pressure rise above this point, melting could occur instead of sublimation.

EQUIPMENT AND PROCESS PARAMETERS

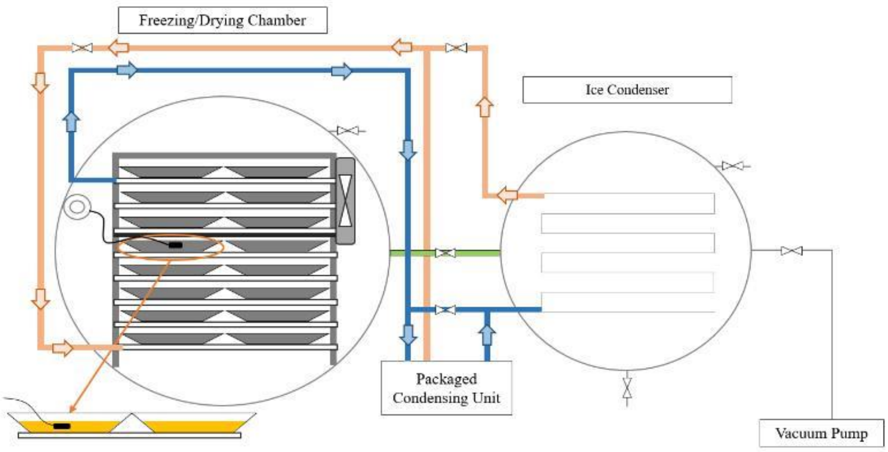

Figure 2: Diagramatic representation of freeze drying

A freeze dryer (lyophilizer) typically consists of a vacuum chamber with temperature-controlled shelves (or plates), a refrigeration unit, a condenser, a vacuum pumps. In batch units, samples are placed on metal shelves that can be heated or cooled via circulating fluid. The refrigeration system chills both condenser coils and shelves, ensuring the product freezes and that sublimated vapour condenses.The vacuum pump maintains the low pressure; water vapour is condensed out on cold coils to protect the pump.Modern freeze dryers also have sensors (e.g. thermocouples in sample vials) and feedback controls to optimize the cycle.

Freeze-dryer range from small laboratory-units units(shelf area ~0.1–1 m²) to large industrial systems (tens of m^2). Lab models are bench-top or cylinder units;production machine can be as large as a walk-in freezer with many shelves or a manifold dryer with hundreds of vials. The key components scale accordingly: larger units use more powerful vacuum pumps and larger condensers (often requiring liquid nitrogen or multistage refrigeration). Process parameters are tuned for each product:

Freezing rate: Rapid cooling (e.g. blast freezer or immersion) produces fine ice crystals. Slow cooling (or annealing cycles) forms larger crystals and open pores. Many formulations use a two-step freeze (fast freeze, brief hold to enlarge crystals) to balance structure and drying time.

Shelf temperature: During primary drying, shelf (or condenser) temperature is set just below the collapse point of the frozen matrix. A typical program starts at -40 °C and gradually rises (e.g. to -20 °C) as ice sublimates. Too high a shelf temperature can cause product collapse; too low extends drying time. In secondary drying, shelves are heated further (e.g. to 20-30 °C) to drive off bound moisture.

Chamber pressure: Primary drying is done at very low pressure (often 100-200mTorr, i.e. 0.013-0.027kPa) to maximize the sublimation rate. In practice, pressures from a few mTorr to a few Torr may be used, depending on product and equipment. Good vacuum (oil-free pumps, molecular pumps) is crucial for efficiency and product purity.

Other factors: include sample load (thicker or larger batches dry slower) and product formulation (adding cryoprotectants or bulking agents can improve drying). Overall freeze-drying requires precise control of temperature, pressure, and time to optimize water removal without damaging the product.

EFFECTS ON FOOD QUALITY

Freeze drying occurs at low temperature without liquid water, that's why it preserves food quality exceptionally well. The frozen state protects chemical structures; nutrients and bioactive are largely retained. For example, freeze-dried fruits and vegetables have been shown to keep most of their vitamins, antioxidants and flavours. A comparative study of dried foods found that almost all free radicals and enzymatic reactions are halted by the freezing/vacuum environment, preventing browning and nutrient loss. One review notes that freeze-dried products have their "Primary structure and shape" preserved with "minimal volume reduction", and that lower processing temperature allow "maximal nutrient and bioactive compound retention"

In practice, this means colour, flavour, and aroma are much better preserved in freeze-drying than in hot air drying. Because oxygen and heat exposure are minimal, pigments and volatiles are less degraded.For instance, freeze-dried strawberry and apple slices show little enzymatic browning (higher lightness* value) compared to air-dried ones. Similarly delicate flavours (e.g. coffee aromatics) are largely retained; instant freeze-dried coffee captures most flavour compounds that would be lost in spray drying. Any volatile compound (e.g. ethanol, acetic acid)may be partially lost during the vacuum process, so some changes in aroma can occur.

Freeze-dried product's texture and structure are also unique. Sublimation leaves a highly porous, open matrix. This porous structure gives freeze-dried foods a light, crispy texture and very rapid rehydration. In short, freeze-drying yields a dried food that looks, tastes and behaves much like the fresh product after reconstitution.

APPLICATIONS IN FOODS

Fruits and vegetables: Many fruits (berries, apples, bananas) and vegetables (peas, corn, tomato) are freeze-dried for use as healthy snacks or ingredients. Freeze-dried fruit "chips" or powders are common in cereals and confectionaries. Their light, crunchy texture and intense flavour make them popular as hiking food and garnishes.

Dairy products: Liquid dairy(milk, cream, yogurt) and cheese have been freeze-dried to make instant powders. For example, whole milk powder and whey protein concentrates are produced by freeze-drying to maximize protein and vitamin retention.

Instant coffee and tea: Perhaps the most familiar freeze-dried products are instant beverages. Brewed coffee or tea is frozen and then lyophilized to form a dry granule that dissolves easily.

Meat, fish and ready-to-eat meals: Meat, sea food(beef,chicken,fish,shrimp) are freeze-dried for use in military rations, emergency relief, and camping meals. Because the process stops microbial growth and locks in nutrients, freeze-dried meats can be stored, shelf -stable and rehydrated with little loss of flavour.

Nutraceuticals and functional foods: Bioactive compounds (vitamins, antioxidants, herbal extracts) are often freeze dried to enhance stability. For example, vitamin C and polyphenol extracts are freeze-dried into powders or capsules, preserving their efficacy.

ADVANTAGES OF FREEZE DRYING:

Highest product quality: It produces highest quality final product. Because drying occurs below the boiling point of water, fragile structure remains intact. Colour, flavour aroma are highly unchanged from the fresh state. Nutrients and phytochemicals (vitamins and antioxidants) suffer minimal losses due to mild temperatures.

Excellent shelf stability: With moisture reduced to ~1–4% and water activity very low, freeze-dried foods are extremely stable. Microbial growth and chemical changes are virtually halted. When hermetically sealed in moisture-and oxygen-proof packaging, freeze dried products can remain shelf stable for years or even decades.

Lightweight and compact: Removing 90-95% of moisture makes the product very light. As a result, freeze-dried foods offer "decreased raw material volume and weight", saving on transportation costs.

Rapid rehydration: The open porous matrix allows freeze-dried foods to absorb water very quickly.This means reconstituted foods regain nearly original texture and juiciness with minimal effort. Many applications (instant coffee, soup mixes, baby foods) rely on this quick rehydration.

Suitable for heat-sensitive and valuable products: Because the process avoids high heat,it can dry materials that would otherwise degrade (fruit purees, pharmaceuticals, enzymes).

CONCLUSION

Freeze-drying is a superior dehydration method that preserves nutrients, flavour, colour,and structure while producing lightweight, shelf stable, easily rehydratable foods. Despite its high energy demand, long processing cycles, and greater cost compared to hot-air or spray drying, its ability to deliver superior nutritional, sensory, and functional properties secures its position as a critical technology for premium and sensitive food products. Ongoing advancements in equipment design, process optimization, and hybrid technologies are expected to reduce costs and improve efficiency, further expanding its application in global food and health industries.

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Recently Recognized Indigenous Livestock Breeds of India

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Introduction

India harbours one of the most diverse livestock populations globally, encompassing a wide spectrum of species including cattle, buffalo, sheep, goat, pig, horse, camel, poultry, and others. Among these, indigenous breeds are particularly esteemed for their adaptability to diverse environmental conditions, resilience to endemic diseases, and efficient utilization of locally available feed resources. Recognizing their strategic importance, the Royal Commission on Agriculture (1926) advocated for systematic research and conservation initiatives to ensure the sustainable utilization of these genetic resources.

The tropical animal and avian genetic resources of India are of considerable national and global significance. Their conservation, evaluation, and certification are imperative for preserving biodiversity and enhancing the productivity of the livestock sector. The ICAR-National Bureau of Animal Genetic Resources (ICAR-NBAGR) plays a central role in the identification, registration, and documentation of indigenous breeds.

As of April 2025, ICAR-NBAGR has officially recognized ten new indigenous breeds: one buffalo, two dogs, two goats, one sheep, one donkey, one duck, one pig, and one yak. With these additions, the total number of registered indigenous breeds in India has reached 230. This includes 54 cattle, 21 buffalo, 41 goat, 46 sheep, 8 horse, 9 camel, 15 pig, 4 donkey, 5 dog, 2 yak, 20 chicken, 4 duck, and 1 geese breed. This extensive genetic repository underscores the need for continued efforts in breed characterization, conservation, and sustainable utilization to support national food security and rural development.

Newly Recognized Indigenous Breeds

Manah Buffalo

The Manah buffalo, recently recognized by ICAR-NBAGR, is indigenous to Assam, particularly the districts of Nalbari, Kamrup, Barpeta, and Goalpara. This medium-sized, dual-purpose breed is primarily reared by smallholder farmers for both milk production and draft purposes, including ploughing and carting. The breed exhibits a black to grey coat color and yields an average of 1.75 kg of milk per day.

Gaddi Dog

The Gaddi dog, named after the Gaddi tribe of Himachal Pradesh, has been officially recognized as an indigenous canine breed. Traditionally utilized by semi-nomadic pastoralists for guarding sheep and goats, the breed is colloquially known as the "Indian Panther Hound" or "Indian Leopard Hound" due to its effectiveness in deterring predators such as the Snow leopard.

Morphologically, the Gaddi dog is characterized by a robust, muscular build, a prominently arched neck, and a predominantly black coat with white markings. With an estimated population of fewer than 1,000 individuals, the breed is at risk of extinction due to genetic dilution and the absence of structured breeding programs. Its recognition is anticipated to catalyze conservation and sustainable management initiatives.

Changkhi Dog

The Changkhi dog, native to the high-altitude cold desert ecosystem of Ladakh, has been recognized as a distinct indigenous breed. This breed plays a critical role in the pastoral systems of the region, serving as a guardian of livestock against apex predators such as Snow leopards and wild canids.

Adapted to extreme climatic conditions, the Changkhi dog possesses a dense, insulating coat, a broad head, and a mane-like fur around the neck and shoulders. Its triangular, drooping ears and sharp-set dark brown eyes reflect its alert temperament. The breed's formal recognition is expected to facilitate targeted conservation and genetic resource management programs.

Ladakhi Donkey

The Ladakhi donkey, locally known as Bombu, is native to the Trans-Himalayan region of Ladakh, including Leh and Kargil districts, thriving at altitudes between 3000–5000 meters above sea level. Adapted to the region's extreme cold, low oxygen, and high UV radiation, these donkeys exhibit remarkable hardiness and surefootedness, making them indispensable for transportation and agricultural tasks in rugged terrains. Characterized by a coat ranging from light brown to dark brown or black with white bellies and distinctive dorsal crosses, they possess compact, sturdy builds with average wither heights around 94 cm. Despite their vital role in local livelihoods and military logistics, their population has declined sharply, highlighting the urgent need for conservation efforts.

Tripureswari Duck

The Tripureswari duck, indigenous to Tripura, is distributed across districts such as Sepahijala, Gomati, Khowai, Dhalai, South Tripura, West Tripura, Unokoti, and North Tripura. It is primarily reared for egg and meat production. By 12 months of age, the breed attains an average body weight of 1.199 kg, with annual egg production ranging from 70 to 101 eggs.

The breed exhibits diverse plumage, predominantly dark brown, with head coloration varying from green, black, and white to brown, grey, and yellowish-brown. The bill, shank, and feet are typically orange or yellow. Despite its potential, the breed faces challenges including limited scientific breeding programs, inadequate nutrition, lack of veterinary support, and restricted market access.

Chaugarkha Goat

The Chaugarkha goat is a small-sized meat breed native to the Chaugarkha Patti region of Uttarakhand, encompassing the districts of Almora, Bageshwar, Champawat, and Pithoragarh. The breed is typically brown, occasionally with white facial stripes, and is well-adapted to the Central Himalayan ecosystem.

Reared under a semi-feral system with minimal supplemental feeding, the Chaugarkha goat thrives on natural forage such as Banj oak. Its hard hooves and low-maintenance requirements make it suitable for mountainous terrains.

Bundelkhandi Goat

The Bundelkhandi goat is native to the Bundelkhand region, spanning southern Uttar Pradesh and northern Madhya Pradesh. It is a medium to large-sized breed with a compact cylindrical body, long legs, and a narrow face with a Roman nose. The coat is black with long hair, and the breed exhibits pendulous ears and a bushy tail. Primarily reared for meat, the Bundelkhandi goat is known for its hardiness and ability to traverse long distances, making it ideal for extensive grazing systems. It is also noted for its prolificacy, often producing twins or triplets.

Karkambi Pig

The Karkambi pig, native to Maharashtra, is primarily reared for meat production. This breed is characterized by its adaptability to local environmental conditions and is an important genetic resource for the region. Despite its significance, comprehensive studies on its phenotypic traits, reproductive performance, and conservation status remain limited. There is a pressing need for systematic research to document its unique characteristics and to develop sustainable breeding and conservation strategies to ensure its preservation.

Kheri Sheep

The Kheri sheep is distributed across the districts of Jodhpur, Nagaur, Ajmer, Tonk, Pali, and Bhilwara in Rajasthan. It is a medium to heavy breed reared for meat, wool, and milk. The coat is predominantly white with black or brown spots around the eyes, nose, ears, and limbs. The breed exhibits a Roman nose, pendulous ears, and a long tail reaching the hock.

Males possess short horns, while females are polled. Approximately 10–15% of the population exhibits wattles. The breed's wool is of high quality, suitable for carpet production. Its adaptability to arid environments and multipurpose utility make it a valuable genetic resource.

Ladakhi Yak

The Ladakhi yak is indigenous to the alpine regions of Leh and Kargil in Ladakh, typically reared at altitudes exceeding 4,000 meters above sea level. These medium-sized animals exhibit a dark brown to black glossy coat, with black muzzles, eyelids, and tail switches. Their horns are curved and oriented laterally upward and backward.

The breed is integral to the livelihoods of high-altitude pastoralists, providing milk, meat, fiber, and draft power. Its recognition underscores the need for conservation of high-altitude livestock genetic resources.

Conclusion

The formal recognition of these ten indigenous breeds by ICAR-NBAGR represents a significant advancement in the documentation and conservation of India's rich livestock biodiversity. These breeds not only contribute to the socio-economic resilience of rural communities but also embody unique genetic traits essential for sustainable livestock development. Continued efforts in breed characterization, scientific management, and policy support are imperative to ensure their long-term viability and integration into national livestock improvement programs.

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Soil Organic Carbon Loss in Tropical Agroecosystems: Drivers, Impacts, and Mitigation Strategies

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1. Introduction

Tropical agroecosystems encompass a vast array of land uses, from traditional shifting cultivation and subsistence farming to intensive monoculture plantations (e.g., oil palm, sugarcane, rice). These systems are critically important for global food security, sustaining the livelihoods of a majority of the world's population, and contributing significantly to global agricultural trade. However, the inherent environmental conditions of the tropics, characterized by consistently high temperatures, intense solar radiation, and often high precipitation, naturally accelerate the biochemical processes governing organic matter decomposition compared to temperate regions. This combination of high natural turnover rates and certain anthropogenic agricultural practices predisposes these soils to rapid organic matter depletion and subsequent Soil Organic Carbon (SOC) loss.

SOC is a fundamental indicator of soil health and soil quality, acting as the primary reservoir for essential plant nutrients (e.g., Nitrogen, Phosphorus, Sulphur) and playing a crucial role in maintaining soil structure, water holding capacity, and microbial diversity. The depletion of SOC, therefore, has profound implications for sustainable agricultural productivity by reducing soil fertility and increasing vulnerability to soil degradation and erosion. Beyond agronomic concerns, SOC is a major component of the terrestrial carbon cycle. The loss of SOC from tropical soils contributes significantly to greenhouse gas emissions, thus exacerbating the challenge of climate change. Conversely, sequestering carbon in these soils offers a powerful natural climate solution.

To effectively manage and mitigate this loss, accurate, rapid, and cost-effective monitoring of SOC and related soil properties is essential. Soil spectroscopy, utilizing techniques such as Visible-Near-Infrared (VNIR) and Mid-Infrared (MIR) reflectance, has emerged as a promising tool for the rapid, non-destructive, and precise quantification of SOC and co-related soil parameters (e.g., EC, pH, P, K). This research-driven approach is vital for assessing the effectiveness of various sustainable land management interventions. This article aims to synthesize the current understanding of SOC loss in tropical agroecosystems, focusing on its specific drivers, multifaceted environmental and agricultural impacts, and a range of potential mitigation strategies necessary for achieving long-term sustainability and climate resilience in the tropics.

2. Drivers of Soil Organic Carbon Loss

The loss of SOC in tropical agroecosystems is a complex process driven by a combination of natural factors and human-induced activities.

2.1. Land-Use Change and Deforestation

The conversion of natural forests and savannas to agricultural land is arguably the most significant driver of SOC loss in the tropics. Forests typically store large amounts of carbon in their biomass and extensive root systems, which contribute significantly to stable soil organic matter.

a. **Forest to Cropland Conversion:** When forests are cleared, often through burning, a substantial portion of above-ground biomass carbon is released as CO_2. The subsequent tilling and cultivation expose previously protected SOC to microbial decomposition and erosion.

b. Pasture Establishment: While less destructive than complete cropland conversion, the establishment of pastures, particularly after forest clearing, can also lead to initial SOC declines, especially if grazing is intensive and leads to compaction and reduced vegetative cover.

2.2. Tillage Practices

Conventional tillage, involving practices like ploughing and harrowing, profoundly impacts soil structure and SOC dynamics.

- **Physical Disturbance:** Tillage breaks up soil aggregates, exposing previously protected organic matter to microbial activity and oxidation.
- **Aeration:** Increased aeration following tillage accelerates the decomposition of organic matter by aerobic microorganisms, leading to CO_2 emissions.
- **Erosion Susceptibility:** Tilled soils, especially on slopes, are more vulnerable to water and wind erosion, which preferentially removes lighter, organic-rich topsoil particles.

2.3. Crop Residue Management

The management of crop residues significantly influences SOC levels.

a. Residue Removal/Burning: In many tropical systems, crop residues are removed for animal feed, fuel, or bedding, or are burned to clear fields for the next planting cycle. This deprives the soil of a crucial input of fresh organic matter, hindering SOC replenishment.

b. Low Biomass Production: Some crops, particularly under nutrient-poor conditions, produce insufficient biomass, contributing minimally to SOC stocks even if residues are retained.

2.4. Lack of Organic Inputs and Fertilization

Reliance solely on inorganic fertilizers without sufficient organic inputs can lead to a decline in SOC. While inorganic fertilizers boost crop yields, they do not directly replenish the organic matter content or improve soil structure in the same way as compost, manure, or cover crops. Continuous cropping without returning organic matter to the soil gradually depletes existing SOC stocks.

2.5. Climatic Factors

Tropical climates inherently contribute to faster SOC turnover.

a. High Temperatures: Elevated soil temperatures accelerate microbial activity, leading to faster decomposition rates of organic matter.

b. Intense Rainfall: Heavy rainfall events, common in the tropics, increase the risk of water erosion, leading to the physical loss of organic-rich topsoil, particularly on exposed or tilled surfaces.

Table 1. Primary Drivers of Soil Organic Carbon Loss in Tropical Agroecosystems

Driver	Mechanism of SOC Loss	Specific Tropical Context
Land-Use Change	Deforestation, burning, and the removal of perennial vegetation	Conversion of rainforests/savannas to croplands/pastures
Conventional Tillage	Soil aggregate disruption, aeration, and increased decomposition	Extensive use of plows for staple crops, e.g., maize, rice
Residue Management	Removal or burning of crop residues	Residues used for fuel/fodder, or burned for pest control/ease of planting
Lack of Organic Inputs	Insufficient addition of biomass, manure, and compost	Limited access to external organic inputs, reliance on inorganic fertilizers
Climatic Factors	High temperatures (accelerated decomposition), intense rainfall (erosion)	Humid tropics, monsoonal climates, high weathering rates
Overgrazing/Degradation	Compaction, reduced vegetation cover, and erosion	Extensive livestock systems, especially in drier tropical regions

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4. Mitigation Strategies for Soil Organic Carbon Loss

Mitigating SOC loss and enhancing carbon sequestration in tropical agroecosystems requires a holistic approach that integrates various sustainable land management practices.

4.1. Conservation Agriculture (CA)

CA is a set of principles that includes minimal soil disturbance, permanent soil cover, and crop rotation.

a. No-Till/Reduced Tillage: Minimizing or eliminating ploughing maintains soil structure, protects organic matter, and reduces CO_2 emissions and erosion.

b. Permanent Soil Cover: Retention of crop residues, cover cropping, or mulching protects the soil surface from erosion, reduces temperature fluctuations, conserves moisture, and provides continuous organic matter input.

c. Crop Rotation/Diversification: Varied crop sequences, including legumes, improve nutrient cycling, suppress pests and diseases, and enhance biomass production, contributing to SOC.

4.2. Agroforestry Systems

Integrating trees with crops and/or livestock offers multiple benefits for SOC sequestration.

a. **Increased Biomass Input:** Trees contribute deep root biomass and leaf litter, enriching SOC at various soil depths.
b. **Reduced Erosion:** Tree canopies and root systems protect the soil from rain impact and stabilize soil structure, minimizing erosion.
c. **Improved Microclimate:** Trees provide shade, reducing soil temperatures and moisture evaporation, which can slow down organic matter decomposition.
d. **Nutrient Cycling:** Leguminous trees can fix atmospheric nitrogen, enhancing overall nutrient availability.

4.3. Organic Amendments and Biochar

Directly adding organic materials to the soil is an effective way to build SOC.

a. **Manure and Compost Application:** Regular application of well-rotted animal manure and compost provides stable organic matter, nutrients, and improves soil physical properties.
b. **Biochar:** Biochar, a charcoal-like material produced from biomass pyrolysis, is highly recalcitrant (resistant to decomposition) and can persist in soil for centuries. Its application can significantly enhance SOC stocks, improve nutrient retention, and increase water holding capacity.

4.4. Improved Residue Management

Retaining crop residues on the soil surface is a cornerstone of SOC building.

a. **Residue Retention:** Educating farmers on the benefits of leaving residues after harvest.
b. **Alternative Uses:** Developing sustainable alternatives for residue use (e.g., composting rather than burning) if removal is unavoidable.

4.5. Enhanced Pasture Management

For tropical pastures, effective management can reverse SOC depletion.

a. **Rotational Grazing:** Moving livestock frequently prevents overgrazing, allowing vegetation to recover and build biomass.
b. **Legume Integration:** Planting leguminous grasses and forages enriches soil nitrogen and increases biomass production.
c. **Silvopastoral Systems:** Integrating trees into pastures combines the benefits of trees with sustainable grazing.

Table 3. Key Mitigation Strategies for Soil Organic Carbon Loss in Tropical Agroecosystems

Strategy	Primary Mechanism for SOC Enhancement	Co-benefits	Specific Tropical Application
Conservation Agriculture	Reduced decomposition, increased residue retention, and aggregation	Erosion control, water conservation, fuel/labour savings	No-till for maize/rice, cover crops for perennial plantations
Agroforestry Systems	Increased biomass input, reduced erosion, improved microclimate	Biodiversity, timber/fruit products, climate resilience	Cocoa/coffee under shade trees, alley cropping, silvopasture
Organic Amendments	Direct addition of stable organic matter	Nutrient supply, improved soil structure, and water retention	Composting urban/agricultural waste, animal manure application
Biochar Application	Long-term carbon sequestration, increased recalcitrance	Improved nutrient/water retention, reduced N_2O emissions	Smallholder farms with access to biomass for pyrolysis
Improved Residue Management	Continuous organic matter input, soil protection	Moisture conservation, weed suppression, and reduced erosion	Leaving residues of sugarcane, maize, and rice on fields
Enhanced Pasture Management	Increased biomass, reduced compaction, improved root systems	Increased forage quality, animal health, and reduced land degradation	Rotational grazing, planting improved forages

4.6. Policy and Economic Incentives

Supportive policies and economic mechanisms can accelerate the adoption of SOC-enhancing practices.

a. **Carbon Credits:** Payments for ecosystem services, where farmers are compensated for sequestering carbon in their soils.

b. **Subsidies/Support:** Providing financial or technical support for farmers adopting CA, agroforestry, or organic amendments.

c. **Research and Extension:** Investing in research tailored to specific tropical conditions and effective extension services to disseminate knowledge to farmers.

5. Conclusion

Soil organic carbon loss in tropical agroecosystems represents a significant and escalating challenge with far-reaching environmental, agricultural, and socio-economic consequences. Driven by a confluence of high decomposition rates inherent to the tropics, land-use change, conventional tillage, and insufficient organic matter returns, SOC depletion directly compromises the physical, chemical, and biological health of the soil. This leads to a vicious cycle of reduced soil fertility, heightened vulnerability to land degradation, and increased on-farm costs due to higher dependency on external inputs.

Crucially, reversing this trend offers a powerful opportunity for a dual dividend: enhancing agricultural productivity and contributing substantially to global climate change mitigation. The widespread adoption of proven, sustainable land management practices, including Conservation Agriculture (CA), agroforestry systems, improved residue management, and the use of organic amendments like manure and biochar, is not merely an optional technique but is are essential strategy for rebuilding SOC stocks. These approaches stabilize the soil matrix, enhance water use efficiency, and sequester atmospheric carbon dioxide.

Achieving success at the necessary scale requires an integrated, multi-disciplinary effort. This necessitates targeted research, particularly leveraging rapid assessment tools like soil spectroscopy, to monitor changes and validate the effectiveness of interventions. Furthermore, it demands enabling policy frameworks, robust extension services, and innovative economic incentives, such as carbon credit schemes, to ensure practices are both ecologically sound and financially viable for smallholder farmers. Investing in SOC sequestration in these vital tropical regions is not just an agricultural imperative; it is a foundational investment in sustainable development, long-term food security, and climate resilience for a rapidly growing global population.

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Functional Role of Soil Enzymes in Nutrient Transportation and Soil Fertility Maintenance

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1. Introduction

Soil, a dynamic living system, is a complex, three-dimensional matrix of minerals, organic matter, water, air, and an astonishing diversity of organisms, collectively known as the soil biome. This living component includes macro- and micro-fauna, as well as a vast array of microbial life (bacteria, fungi, archaea). Within this intricate environment, soil enzymes are pivotal biochemical catalysts that mediate a myriad of biogeochemical processes essential for nutrient cycling and the maintenance of soil fertility. Produced primarily by microorganisms but also by plant roots (through rhizodeposition) and soil fauna, these enzymes act as the workhorses of the soil, driving the essential transformation of complex, recalcitrant organic matter (such as cellulose, lignin, and complex proteins) into simpler, plant-available forms.

The functional significance of soil enzymes extends beyond simple decomposition. They regulate the mobilization and immobilization of nutrients like nitrogen, phosphorus, and sulphur, fundamentally controlling the flux of these elements between the organic pool and the plant-available inorganic pool. Enzyme activity is not merely a consequence of biological presence; it is a sensitive and integrated indicator of soil health and quality. Enzyme levels respond rapidly to changes in land use, such as the shift from native vegetation to intensive cropping, and to various agricultural practices, including tillage intensity, fertilization regimes, and the application of organic amendments. Consequently, monitoring specific enzyme activities provides an early, quantifiable measure of stress or improvement in soil ecological function. Understanding the precise mechanisms by which soil enzymes operate and influence nutrient dynamics is crucial for developing and implementing sustainable agricultural strategies that aim to enhance soil fertility, optimize nutrient use efficiency, and ensure long-term crop productivity while minimizing environmental impacts.

2. Origin and Classification of Soil Enzymes

Soil enzymes originate from various sources, predominantly microorganisms (bacteria, fungi, actinomycetes), but also from plant roots (rhizodeposition) and soil animals. Upon death, these organisms release their intracellular enzymes into the soil matrix, where they become adsorbed onto clay minerals, organic colloids, or remain in the extracellular solution. This adsorption often protects enzymes from denaturation and proteolytic degradation, extending their functional lifespan in the soil.

Table 4. Major Soil Enzymes and Their Substrates

Enzyme Type	Substrate	Nutrient Released/Process Catalyzed
Hydrolases		
Phosphatases	Organic phosphorus compounds (phytate, DNA)	Inorganic phosphate (PO_4^{3-})
Urease	Urea	Ammonia (NH_3), Carbon dioxide (CO_2)
β-Glucosidase	Cellulose, hemicellulose	Glucose, other simple sugars
Cellulase	Cellulose	Glucose
Arylsulfatase	Organic sulphur compounds	Sulphate (SO_4^{2-})
Proteases	Proteins, peptides	Amino acids, ammonia
Oxidoreductases		
Dehydrogenase	Organic substrates	Indicator of microbial activity, carbon oxidation
Peroxidase	Phenolic compounds	Detoxification, humification
Polyphenol oxidase	Phenolic compounds	Detoxification, humification

Soil enzymes can be broadly classified based on the type of biochemical reaction they catalyze:

a. Hydrolases: Break down complex organic molecules using water. Examples include phosphatases, urease, glucosidases, and cellulases.

b. Oxidoreductases: Catalyze oxidation-reduction reactions. Examples include dehydrogenases, peroxidases, and polyphenol oxidases.

c. Transferases: Transfer functional groups between molecules.

d. Lyases: Break chemical bonds without hydrolysis or oxidation.

e. Isomerases: Catalyze the rearrangement of atoms within a molecule.

f. Ligases: Catalyze the joining of two large molecules by forming a new chemical bond.

3. Role in Nutrient Transportation and Cycling

Soil enzymes are the central molecular machinery orchestrating the global biogeochemical cycles of the essential macronutrients: carbon (C), nitrogen (N), phosphorus (P), and sulphur (S). Their activity dictates the rate and efficiency at which these nutrients are released from complex organic reservoirs and made available for plant uptake, thus directly determining the fertility of the soil system.

3.1. Carbon Cycling

Carbon cycling is the foundational process for energy flow and the formation of soil organic matter (SOM), which provides the physical, chemical, and biological basis for fertile soil. Enzymes drive the crucial step of breaking down complex, high-molecular-weight organic compounds derived from plant and microbial residues:

a. Cellulases and **ß-Glucosidases:** These hydrolases are responsible for the cleavage of glycosidic bonds in cellulose and hemicellulose, the most abundant organic polymers in plant residues. This action releases simple sugars (like glucose), which serve as the primary energy source for the heterotrophic soil microbial community.

b. Amylases and **Xylanases:** These enzymes similarly hydrolyze starch and xylan, respectively, further contributing to the pool of readily metabolizable carbon.

c. Dehydrogenases: These oxidoreductases are intracellular enzymes involved in the biological oxidation of organic substrates. While not directly involved in extracellular decomposition, their activity is a widely accepted measure of the overall metabolic activity and vitality of the microbial biomass, thus serving as a general proxy for the intensity of carbon cycling and energy flux in the soil.

3.2. Nitrogen Cycling

Nitrogen is a critical component of proteins, nucleic acids, and chlorophyll, making its availability paramount for plant productivity. Soil enzymes are central to the mineralization (the conversion of organic N to inorganic N) pathway:

a. Proteases (e.g., Peptidases): These enzymes initiate the process by hydrolyzing large protein molecules and peptides, which constitute a major N reservoir, into smaller amino acids.

b. Urease: This is one of the most studied soil enzymes, specifically responsible for the rapid hydrolysis of urea (both natural and applied fertilizer) into ammonia (NH_3) and carbon dioxide (CO_2). The rapid release of ammonia subsequently leads to the formation of the plant-available ammonium (NH_4^+) ion.

$$Urea + H_2O \xrightarrow{Urease} Ammonia + CO_2$$

c. Amidases: These enzymes act on amides, also releasing NH_4.

The resulting NH_4 can either be directly absorbed by plants or converted to nitrate (NO_3) via the microbially mediated process of nitrification, involving the intracellular enzymes of *Nitrosomonas* and *Nitrobacter* bacteria. Enzyme activities in the N cycle are tightly regulated; for example, high NH_4 concentrations can sometimes suppress the production of urease by microorganisms.

3.3. Phosphorus Cycling

Phosphorus is often a limiting nutrient in agricultural systems due to its low solubility and availability. A significant portion of soil P is present in organic forms (e.g., phytate, phospholipids, nucleic acids). Phosphatases (acid and alkaline phosphatases, phosphodiesterases) are the primary enzymes responsible for hydrolyzing these organic P compounds, releasing inorganic orthophosphate (PO_4^{3-}), which is the form readily absorbed by plants. The activity of phosphatases is often induced under P-limited conditions, highlighting their adaptive significance in nutrient acquisition.

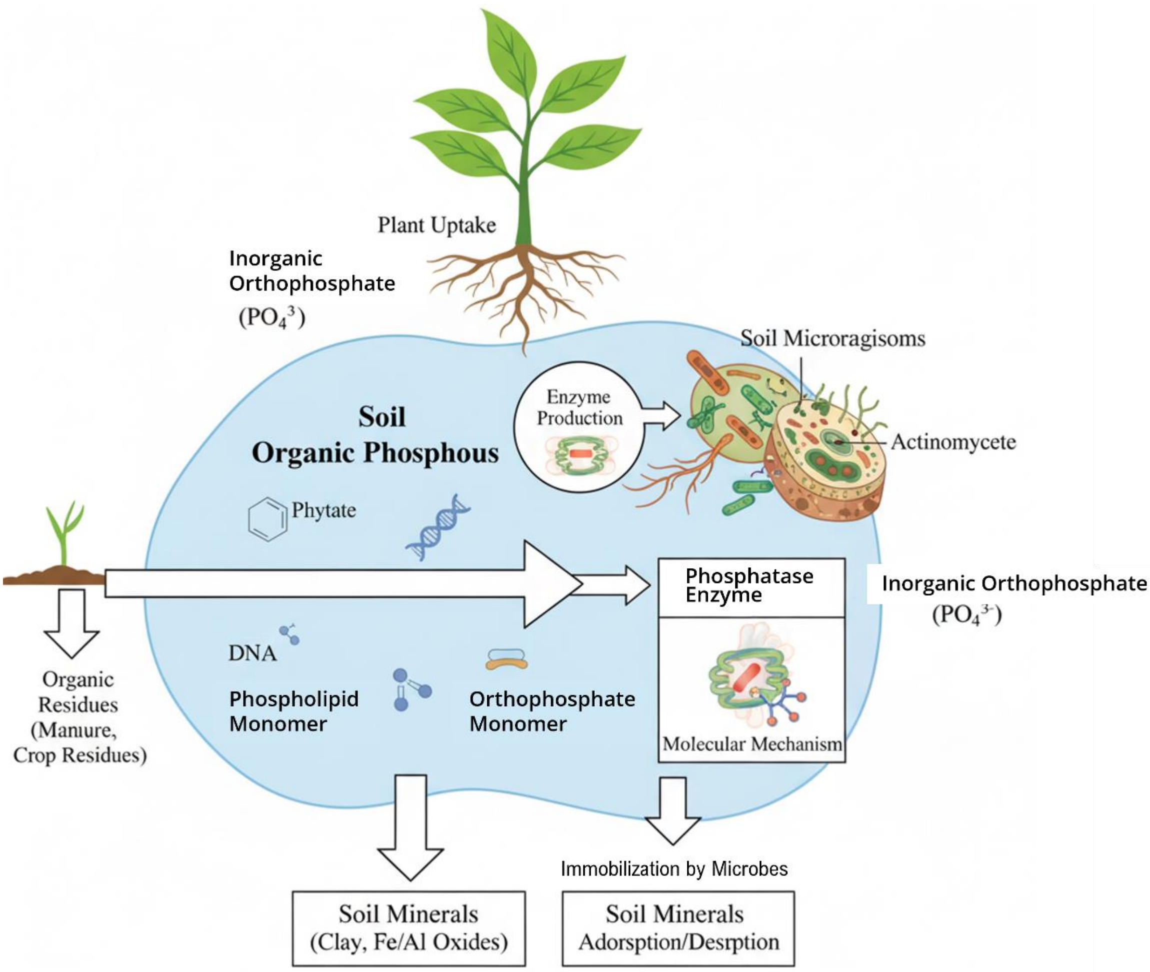

Figure 2. Role of Phosphatase in Phosphorus Cycling

3.4. Sulphur Cycling

Sulphur is essential for amino acid synthesis (cysteine, methionine) and key enzyme function. In most soils, organic sulphur compounds represent the major reservoir, making mineralization a critical step for plant nutrition.

- Arylsulfatase: This is the dominant enzyme in the S cycle, functioning as a hydrolase to cleave the ester sulphate bond in organic sulphate esters (e.g., phenolic sulphates and choline sulphates). This reaction releases the plant-available inorganic form, sulphate (SO_4^{2-}).

$$Organic\ Sulphate\ Ester\ + H_2O \xrightarrow{Arylsulphatase} Sulphate\ +\ Phenol/Alcohol$$

The activity of arylsulfatase is vital for ensuring a continuous supply of S to plants, particularly in soils relying heavily on organic matter turnover for nutrient delivery.

4. Soil Enzymes as Indicators of Soil Fertility and Health

Soil enzymes are now widely recognized as sentinels of soil quality and functional biodiversity, offering a sensitive and comprehensive measure of the biological processes underpinning soil fertility. Unlike traditional chemical analyses that measure the size of a nutrient pool (e.g., total organic carbon or available phosphorus), enzyme activity measures the rate or intensity of the biological transformations, the actual process of nutrient cycling. This makes them highly effective and early indicators of changes in the soil environment.

4.1. Sensitivity to Disturbances and Management

The activity of soil enzymes reflects the instantaneous physiological state of the microbial community, making them remarkably responsive to both natural stresses and anthropogenic disturbances:

a. **Sensitivity to Environmental Stress:** Enzymes respond rapidly to abiotic stresses. For instance, prolonged drought or extreme temperature shifts quickly lead to a reduction in enzyme activity due to decreased microbial metabolic rates and altered enzyme stability. Conversely, the introduction of a pollutant, such as a heavy metal or a specific pesticide, can cause an immediate and significant inhibition of key enzymes (e.g., urease, acid phosphatase) by binding to their active sites or denaturing their structure.

b. Response to Management Practices:

- **Tillage: Intensive conventional tillage** generally decreases enzyme activity, particularly in the topsoil, by disrupting soil aggregates, physically dispersing microbial habitats, and accelerating the oxidation of organic matter, which reduces the substrate pool. No-till or conservation tillage practices, conversely, tend to increase enzyme levels by fostering a stable environment rich in organic residues, leading to higher microbial biomass and activity.
- **Fertilization and Amendments:** The application of organic amendments (e.g., manure, compost) typically results in a pronounced increase in overall enzyme activity by introducing enzymes directly and, more importantly, by supplying abundant new substrate and stimulating indigenous microbial growth. Conversely, excessive application of synthetic fertilizers (especially nitrogen or phosphorus) can lead to repression of the specific enzymes responsible for the natural cycling of those nutrients (e.g., high inorganic P can repress phosphatase production) as the nutrient is no longer limiting.

4.2. Correlation with Soil Quality Parameters

Enzyme activities provide crucial links to the three pillars of soil health: physical, chemical, and biological.

a. Biological Activity and Biomass: The activity of enzymes like dehydrogenase (an intracellular enzyme associated with cell respiration) serves as an excellent general proxy for the size and metabolic vitality of the microbial biomass. High dehydrogenase activity is a strong indicator of an active and thriving microbial community.

b. Soil Organic Matter (SOM): Enzyme activities show a strong positive correlation with SOM content. SOM not only serves as the source of enzyme substrates but also acts as a protective matrix, stabilizing extracellular enzymes by adsorption onto clay-humus complexes, thereby extending their functional lifespan in the soil.

c. Nutrient Availability Potential: High activities of hydrolytic enzymes (e.g., urease, acid phosphatase, arylsulfatase) indicate a greater potential for the rapid mineralization of organic reserves. This suggests that the soil ecosystem is functionally capable of maintaining a steady, efficient supply of plant-available N, P, and S. For instance, measuring the ratio of C-acquiring enzymes to N or P-acquiring enzymes can indicate which nutrient is limiting microbial activity and, subsequently, plant growth.

4.3. Advantages over Traditional Indicators

Enzymes offer several distinct advantages over traditional physicochemical soil tests:

a. Early Warning System: They are more sensitive and respond faster to changes than total organic matter or stable chemical pools, providing an early warning system for soil degradation or restoration.

b. Integrated Measure: They integrate the complex interactions between soil microbes, organic matter, and the physical environment into a single, functional measurement.

c. Functional Status: They provide information on the functional capacity of the soil, its ability to *perform* vital ecological services rather than just its static chemical composition.

5. Factors Influencing Soil Enzyme Activity

Several factors influence the activity and stability of soil enzymes:

a. Soil pH: Each enzyme has an optimal pH range for activity. Extreme pH values can lead to enzyme denaturation.

b. Temperature: Enzyme activity generally increases with temperature up to an optimum, beyond which denaturation occurs.

c. Substrate Availability: The presence and concentration of specific substrates are crucial for enzyme function.

d. Moisture Content: Water is essential for enzymatic reactions and microbial life. Both very dry and waterlogged conditions can inhibit activity.

e. Heavy Metals and Pollutants: Many contaminants can inhibit enzyme activity by binding to active sites or altering enzyme structure.

f. **Clay Minerals and Organic Colloids:** Adsorption to these particles can stabilize enzymes against proteolysis and denaturation, but can also reduce activity by altering enzyme conformation or limiting substrate access.

g. **Microbial Biomass and Diversity:** A larger and more diverse microbial community generally leads to higher enzyme activity and a wider range of enzymatic functions.

Table 5. Impact of Agricultural Practices on Soil Enzyme Activity

Agricultural Practice	Potential Impact on Enzyme Activity (General Trend)	Explanation
Conventional Tillage	Decrease	Disrupts microbial habitats, increases aeration, and accelerates organic matter decomposition.
No-Till/Conservation Tillage	Increase	Preserves soil structure, increases organic matter, favors microbial growth, and reduces erosion.
Organic Amendments (Manure, Compost)	Increase	Introduces enzymes, provides substrate, stimulates microbial biomass, and enzyme production.
Synthetic Fertilizers	Variable (Often decreases or no change, depending on nutrient)	It can suppress specific enzyme activities if nutrients are no longer limiting and alter soil pH.
Pesticide Application	Decrease	Toxic to microorganisms, it can directly inhibit enzyme function.
Cover Cropping	Increase	Adds organic matter, supports diverse microbial communities, and protects soil from erosion.

6. Conclusion and Future Directions

Soil enzymes are indispensable components of the soil ecosystem, acting as critical intermediaries in nutrient cycling and organic matter decomposition. Their collective activity underpins soil fertility, supporting plant growth and overall ecosystem productivity. As sensitive indicators, they offer valuable insights into the health and functional status of agricultural soils.

Moving forward, research should focus on:

1. **Developing more rapid and cost-effective methods for enzyme activity assessment:** This will facilitate their routine use in soil health monitoring.
2. **Understanding the complex interactions between different enzyme systems:** Elucidating how enzyme networks function, rather than individual enzymes, will provide a more holistic view of nutrient cycling.
3. **Investigating the impact of emerging agricultural technologies and climate change on enzyme dynamics:** Predictive models based on enzyme activity could inform adaptive management strategies.
4. **Harnessing engineered enzymes or microbial consortia for targeted nutrient release:** This could lead to novel biofertilizer approaches.

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Optimizing Water Use Efficiency in Integrated Agriculture–Aquaculture Systems: A Comparative Analysis of Irrigation Practices

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1. Introduction

The escalating global population and the concomitant increase in demand for food and freshwater resources exert immense pressure on agricultural and aquacultural sectors. High water footprints and significant environmental impacts often characterize traditional mono-cropping and intensive aquaculture practices. Integrated agriculture–aquaculture (IAA) systems emerge as a promising paradigm for sustainable food production, where the waste products from one component serve as inputs for another, thereby closing nutrient loops and enhancing resource efficiency (Prein, 2002; Little *et al.*, 2018).

Water, a finite and increasingly scarce resource, is central to both agriculture and aquaculture. Optimizing its use within IAA systems is not merely an economic imperative but also an ecological necessity. Water use efficiency (WUE) is a critical metric for assessing the sustainability and productivity of these integrated systems. It quantifies the amount of biomass produced per unit of water consumed or applied. Enhancing WUE in IAA systems can lead to reduced operational costs, minimized environmental pollution (e.g., nutrient runoff), and increased resilience to water scarcity (FAO, 2017).

2. Integrated Agriculture–Aquaculture Systems: An Overview

IAA systems are diverse and can range from simple fish ponds with adjacent agricultural plots utilizing pond water for irrigation to more complex aquaponic systems where aquaculture effluent directly nourishes hydroponically grown crops. The fundamental principle is the symbiotic relationship between the aquatic and terrestrial components. Fish waste, rich in nutrients like nitrogen and phosphorus, can be a valuable fertilizer for crops, while plants can help filter water for the aquaculture component (Rakocy *et al.*, 2006; Konnerup *et al.*, 2016).

2.1. Typologies of IAA Systems

Table 6. Common Typologies of Integrated Agriculture–Aquaculture Systems

System Type	Description	Water Interaction
Pond-Based Systems	Fish ponds integrated with adjacent agricultural fields (e.g., rice-fish culture, vegetable-fish culture).	Pond water is used for irrigation; agricultural runoff may return to ponds.
Aquaponics	Recirculating aquaculture system (RAS) coupled with hydroponic crop production.	Highly efficient water recirculation; minimal water loss beyond evapotranspiration and sludge removal.
Ducks/Poultry on Ponds	Ducks or poultry are raised on platforms over fish ponds, their droppings fertilizing the water and feeding fish.	Indirect water interaction: nutrient transfer from animal waste to pond water.
Wastewater-Fed Systems	Untreated or partially treated domestic/agricultural wastewater is used for aquaculture, with subsequent use of pond water for irrigation.	Utilizes unconventional water sources; requires careful management to avoid contamination.
Silvo-aquaculture	Integration of trees/forestry with aquaculture, often involving the use of pond effluent for tree irrigation.	Trees provide shade, reduce evaporation, and provide nutrients used for tree growth.

3. Water Use Efficiency in IAA Systems

Water use efficiency (WUE) in agricultural contexts is typically defined as the ratio of crop yield to the amount of water consumed or applied. In IAA systems, this definition expands to consider the overall productivity of both the aquatic and terrestrial components relative to the total water input into the system.

3.1. Key Metrics for WUE Assessment

a. **Crop Water Use Efficiency (CWUE):** (Crop Yield / Evapotranspiration or Water Applied).
b. **Fish Water Use Efficiency (FWUE):** (Fish Biomass Gain / Water Consumed or Used in Culture).
c. **System Water Use Efficiency (SWUE):** (Total Biomass Output (crop + fish) / Total Water Input to System).

The goal is to maximize SWUE, meaning more food is produced per unit of water across the entire integrated system. This often involves minimizing losses through evaporation, deep percolation, and runoff, and maximizing the reuse of water and nutrients.

4. Comparative Analysis of Irrigation Practices

This section critically examines various irrigation practices within IAA systems, evaluating their impact on WUE.

4.1. Traditional Irrigation Methods

Traditional irrigation practices, while often simple and low-cost, are generally characterized by lower WUE due to significant water losses.

4.1.1. Furrow Irrigation

Furrow irrigation involves directing water down furrows between crop rows. In IAA systems, water from fish ponds can be gravity-fed into these furrows.

a. **Advantages:** Low initial cost, simple to operate, suitable for various soil types.
b. **Disadvantages:** High water losses through deep percolation and runoff, uneven water distribution, leading to varied crop growth. WUE is typically low (30-60%).
c. **Relevance to IAA:** Pond water rich in nutrients can directly fertilize crops. However, the large volume of water required can deplete pond levels quickly, especially in arid regions.

4.1.2. Flood/Basin Irrigation

This method involves flooding an entire field or basin with water. It is common in rice-fish culture where the rice paddies are intermittently or continuously flooded.

a. **Advantages:** Simple, can effectively leach salts from the root zone, suitable for rice cultivation.
b. **Disadvantages:** Very high-water losses through evaporation, deep percolation, and lateral seepage. WUE is often the lowest among irrigation methods (20-50%).
c. **Relevance to IAA:** Essential for rice-fish systems, where the water body serves both crop growth and fish habitat. However, outside of rice, its application for other crops is highly inefficient.

4.2. Advanced and Pressurized Irrigation Systems

These systems offer significant improvements in water delivery precision and uniformity, leading to higher WUE.

4.2.1. Sprinkler Irrigation

Sprinkler systems deliver water through overhead sprinklers, mimicking rainfall. They can be adapted to use pond water, often requiring pumping and filtration.

a. **Advantages:** Higher application efficiency (60-85%) compared to surface methods, suitable for undulating terrains, uniform water distribution with proper design.
b. **Disadvantages:** Higher initial cost, susceptible to wind drift and evaporation losses, especially in hot and dry climates. Requires energy for pumping.
c. **Relevance to IAA:** Pond water can be effectively distributed, but clogging of nozzles from suspended solids in pond water can be an issue, necessitating filtration.

4.2.2. Drip/Micro-irrigation

Drip irrigation delivers water directly to the plant root zone through emitters, minimizing losses. It is highly suitable for vegetables and perennial crops.

a. **Advantages:** Very high application efficiency (85-95%), minimal evaporation and runoff, precise nutrient delivery (fertigation) with pond water, reduced weed growth.

b. **Disadvantages:** Higher initial cost, clogging of emitters from suspended solids (requiring robust filtration), potential for salt accumulation in the root zone if water quality is poor.

c. **Relevance to IAA:** One of the most promising methods for integrating pond water into agriculture. Allows for targeted delivery of nutrient-rich pond effluent, maximizing both water and nutrient use efficiency. Filtration is critical.

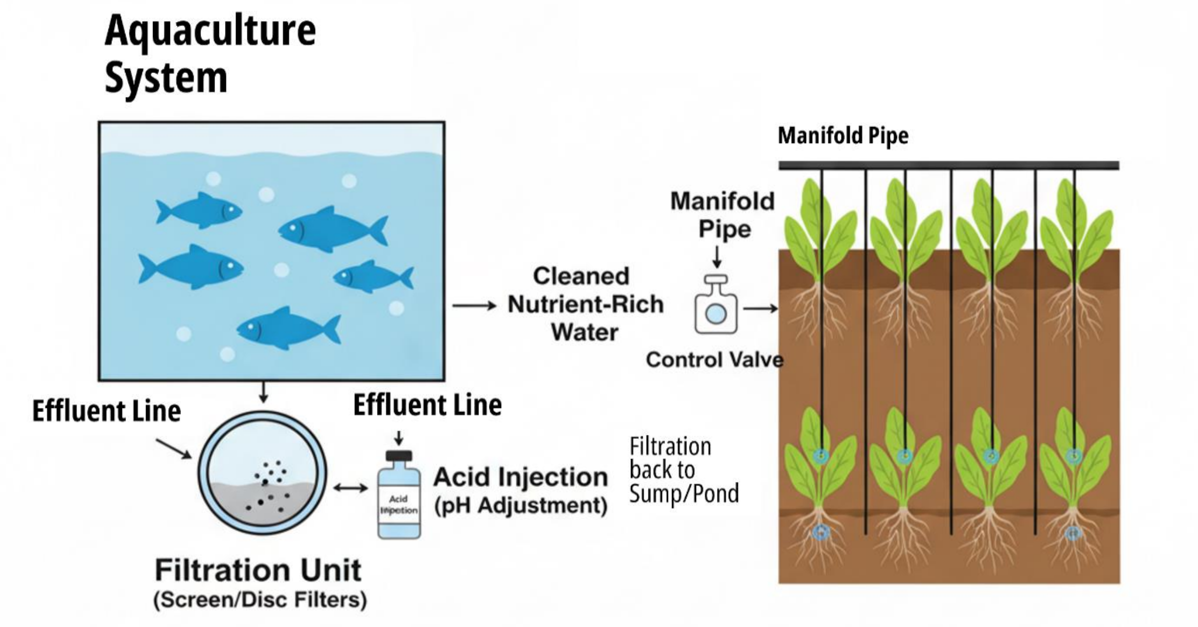

Figure 3. Drip Irrigation System Utilizing Aquaculture Effluent

4.2.3. Subsurface Drip Irrigation (SDI)

SDI is a variant of drip irrigation where the drip lines are buried below the soil surface, directly delivering water to the root zone.

a. **Advantages:** Even higher WUE than surface drip (90-98%), virtually eliminates evaporation from the soil surface, prevents runoff, is less susceptible to animal damage, and allows for cultivation immediately after irrigation.

b. **Disadvantages:** High initial cost, more complex installation and maintenance, difficulty in detecting and repairing clogs, potential for root intrusion into emitters. Requires even more rigorous filtration of pond water.

c. **Relevance to IAA:** Offers superior water and nutrient delivery for crops using aquaculture effluent, especially for perennial crops or those with deeper root systems. The nutrient-rich water can be delivered directly where needed, reducing losses.

4.3. Innovative and Highly Integrated Approaches

These approaches represent advanced levels of integration, often blurring the lines between the aquatic and terrestrial components.

4.3.1. Aquaponics

Aquaponics is a closed-loop system combining aquaculture and hydroponics, where nutrient-rich water from the fish tank is circulated to feed hydroponically grown plants, which in turn filter the water for the fish.

a. **Advantages:** Extremely high WUE (recycles 90-99% of water compared to traditional agriculture), continuous nutrient supply to plants, reduced need for synthetic fertilizers, year-round production in controlled environments. Minimal land footprint.

b. **Disadvantages:** High initial investment, requires technical expertise for management, susceptible to system imbalances (e.g., pH, nutrient deficiencies), limited range of suitable crops and fish species.

c. **Relevance to IAA:** Represents the pinnacle of water and nutrient recycling in IAA. Maximizes productivity per unit of water, making it ideal for urban farming or water-scarce regions. No external irrigation in the traditional sense, as plants are watered by the circulating aquaculture effluent.

4.3.2. Constructed Wetlands for Effluent Treatment and Reuse

Constructed wetlands can be used to treat aquaculture effluent, and the treated water can then be used for irrigation. While not strictly an "irrigation practice" itself, it facilitates the reuse of water.

a. **Advantages:** Natural, low-cost water treatment, removes suspended solids and nutrients, creates habitat, treated water can be safely used for conventional irrigation.
b. **Disadvantages:** Requires land area, treatment efficiency can vary with temperature and plant growth, potential for pathogen concerns if not properly designed and managed.
c. **Relevance to IAA:** Improves the quality of aquaculture effluent, making it safer and more effective for use with high-efficiency irrigation systems like drip or SDI, especially where pathogen concerns might otherwise preclude direct use.

5. Factors Influencing Irrigation Practice Selection in IAA Systems

The optimal choice of irrigation practice for an IAA system is contingent upon several interacting factors:

5.1. Water Source and Quality

The choice of water source (e.g., pond water, treated effluent, municipal water) determines the necessary filtration level and potential clogging risks. Aquaculture effluent, while nutrient-rich, may contain suspended solids, algae, and pathogens, warranting careful consideration for direct application, particularly with micro-irrigation systems.

5.2. Crop and Fish Species

Different crops have unique water requirements and tolerances. For instance, rice-fish systems are suited to flood irrigation, while vegetables benefit from drip irrigation. The sensitivity of specific fish species to water quality changes also shapes the design of irrigation and recirculation systems.

5.3. Climate and Soil Type

In arid climates, efficient irrigation methods are crucial to reduce evaporation losses. Sandy soils, with their low water retention capacity, require more frequent, smaller water applications, making them suitable for drip or subsurface drip irrigation (SDI). Conversely, clayey soils hold water longer but risk waterlogging if over-irrigated.

5.4. Economic Considerations

The initial capital investment, operational costs (including energy for pumping, filtration, and maintenance), and labor needs vary widely among irrigation systems. High-tech systems like aquaponics and SDI typically have higher upfront costs but can lead to long-term savings in water and fertilizer, along with potentially higher yields.

5.5. Farmer's Expertise and Management Capacity

Implementing complex irrigation systems necessitates technical knowledge for installation, operation, and maintenance. Providing adequate training and support is essential for the successful adoption of advanced irrigation practices.

6. Enhancing Water Use Efficiency Beyond Irrigation Methods

Beyond selecting the appropriate irrigation technology, several complementary strategies can further enhance WUE in IAA systems:

6.1. Smart Irrigation Scheduling

Utilizing sensor-based systems (soil moisture sensors, weather stations) and predictive models to determine precise irrigation timing and amounts can significantly reduce water waste.

6.2. Water Storage and Rainwater Harvesting

Collecting rainwater and storing excess pond water can buffer against periods of water scarcity, improving overall system resilience.

6.3. Evaporation Reduction Techniques

Techniques like mulching (for terrestrial crops), floating covers on aquaculture ponds, and the use of windbreaks can minimize evaporative losses.

6.4. Integrated Pest and Disease Management

Healthy plants and fish are more efficient users of water and nutrients. IPM practices reduce stress and ensure optimal growth, indirectly contributing to WUE.

6.5. Genetic Selection

Developing or selecting crop varieties and fish strains that are more water-efficient or tolerant to specific water qualities can improve overall system performance.

7. Challenges and Future Directions

Despite the clear benefits, several challenges need to be addressed to further optimize WUE in IAA systems:

7.1. Water Quality Management

The chemical and biological quality of aquaculture effluent can be highly variable. Ensuring appropriate treatment (filtration, pathogen removal) before irrigation, especially for food crops, is paramount. Developing robust, low-cost filtration solutions is a key research area.

7.2. Nutrient Balancing

While aquaculture effluent is rich in N and P, it may be deficient in other essential micronutrients for specific crops. Supplementation or careful species selection is necessary. Understanding the precise nutrient dynamics in different IAA configurations is crucial.

7.3. Policy and Regulatory Frameworks

Existing policies often separate agriculture and aquaculture, hindering integrated development. There is a need for supportive policies that encourage IAA adoption and facilitate the use of treated wastewater.

7.4. Technology Transfer and Extension

Bridging the gap between research and practice is vital. Farmers need access to appropriate technologies, training, and extension services to successfully implement and manage efficient irrigation practices in IAA systems.

7.5. Economic Viability and Market Access

The economic feasibility of implementing advanced irrigation systems in IAA needs to be thoroughly assessed, considering local market conditions and potential for premium pricing for sustainably produced goods.

Future research should focus on:

a. **Development of robust, low-cost filtration and treatment technologies** for aquaculture effluent for various irrigation methods.

b. **Integrated modeling tools** that predict water and nutrient dynamics across different IAA configurations.

c. **Crop and fish breeding programs** focused on water use efficiency and symbiotic compatibility within IAA systems.

d. **Socio-economic studies** to understand farmer adoption drivers and barriers for efficient IAA practices.

e. **Life cycle assessments** to comprehensively evaluate the environmental footprint of different IAA systems and irrigation practices.

8. Conclusion

Optimizing water use efficiency in integrated agriculture–aquaculture systems is critical for achieving sustainable food production in a world facing increasing water scarcity. The comparative analysis reveals that advanced irrigation methods like drip, subsurface drip, and particularly aquaponics, offer significantly higher WUE compared to traditional surface irrigation. These technologies enable the precise delivery of nutrient-rich aquaculture effluent to crops, maximizing both water and nutrient utilization.

However, the selection of an appropriate irrigation practice must be holistic, considering water quality, crop and fish requirements, climate, soil type, and economic realities. Moving forward, concerted efforts in research, technology development, policy support, and farmer training are essential to unlock the full potential of IAA systems as highly water-efficient and environmentally sustainable food production platforms. By embracing integrated approaches and optimizing irrigation strategies, IAA systems can play a pivotal role in global food and water security.

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Rice–Fish Farming Systems: Assessing Economic Viability, Ecological Benefits, and Operational Challenges

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1. Introduction

The global agricultural landscape faces the dual imperative of enhancing food security for a growing population while simultaneously mitigating the environmental footprint of intensive farming practices. Conventional rice monoculture, a staple food source for over half the world's population, is often associated with significant environmental concerns, including high water usage, greenhouse gas emissions, and reliance on synthetic agrochemicals. In response to these challenges, integrated farming systems (IFS) have emerged as promising alternatives, offering synergistic benefits that transcend the sum of individual components. Among these, the rice–fish farming system (RFS) stands out as a time-tested yet innovative approach that harnesses the symbiotic relationship between rice cultivation and aquaculture.

RFS, a practice historically observed for centuries in various parts of Asia, involves the deliberate introduction and cultivation of aquatic organisms, predominantly fish, within rice paddies or adjacent water bodies. This integration fosters a unique agro-ecological environment where each component supports the other, leading to a more resilient, productive, and sustainable farming system. The renewed interest in RFS is driven by its potential to contribute significantly to the United Nations Sustainable Development Goals (SDGs), particularly those related to zero hunger, good health and well-being, clean water and sanitation, and life on land.

2. Typologies and Design of Rice–Fish Farming Systems

Rice–Fish Farming Systems (RFS) vary based on local agro-climatic conditions, socio-economic factors, and the species cultivated. RFS is mainly categorized into two types: simultaneous and rotational systems

2.1. Simultaneous RFS

In simultaneous systems, rice and fish are cultured together in the same paddy field, making it the most common RFS type. Key subdivisions include:

a. **Paddy-cum-Fish Culture:** Fish are reared directly within the rice field throughout the growing season, often utilizing trenches, ponds, or refuges to provide deeper water areas for fish during low water periods or harvesting.

b. **Rice-Fish Integrated Systems:** This involves advanced management techniques where water levels are controlled, and fish stocking densities are optimized to balance growth and rice yield.

2.2. Rotational RFS

Rotational systems cultivate rice and fish at different times within the same field:

a. **Rice followed by Fish:** Rice is grown in one season, and after harvest, the field becomes a temporary pond for fish during the off-season, commonly in regions with wet and dry seasons.

b. **Fish followed by Rice:** Less common, this system begins with fish culture to enrich the soil with fish excreta before rice planting.

2.3. Design Considerations

Effective RFS design considers several factors:

a. **Bund Height and Strength:** Elevated, reinforced dikes are essential to retain water and prevent fish escape.

b. **Trenches/Refuges:** Deep channels (20-50 cm deep, 50-100 cm wide) provide refuge for fish during dry spells or pesticide applications.

c. **Water Inlets and Outlets:** Screens or nets are needed to avoid fish escape and the entry of predatory species.

d. **Species Selection:** Choosing appropriate rice varieties (ideally, flood-tolerant and sturdy) and fish species (herbivorous or omnivorous, fast-growing, and market-demanded such as carp and tilapia) is crucial for success.

Table 7. Common Rice and Fish Species Combinations in RFS

Rice Variety Type	Representative Fish Species	Key System Benefit	Geographic Focus
High-Yielding Varieties (HYVs)	**Common Carp** (*Cyprinus carpio*)	**Soil Aeration** & Natural Fertilization	Asia (China, India, Indonesia)
Deep-water/Flood-tolerant Rice	**Tilapia** (*Oreochromis niloticus*)	High resilience & **Pest Control**	Southeast Asia (Mekong, Bangladesh)
Traditional/Local Varieties	**Catfish** (*Clarias* spp.)	**Survival in Low Oxygen** & Drought Tolerance	Localized/Africa/Asia

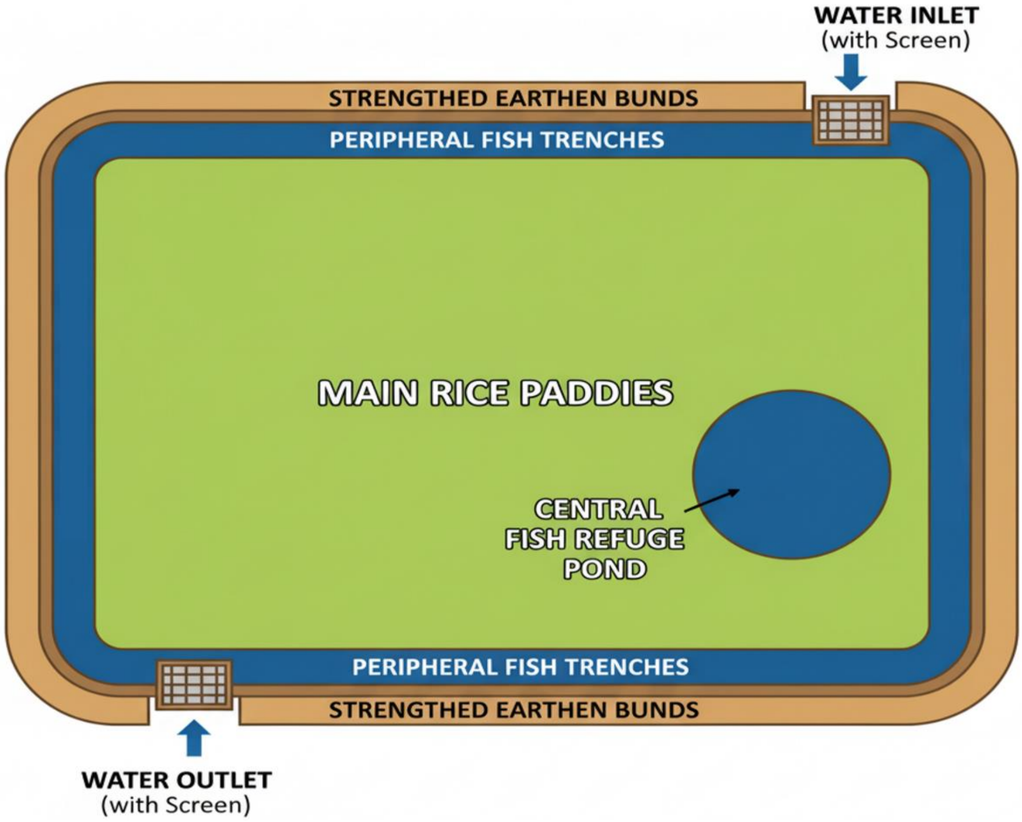

Figure 4. Typical Layout of a Simultaneous Rice-Fish Farm

This diagram would illustrate the main components: rice area, peripheral trenches, strengthened bunds, water inlet/outlet with screens, and a small central pond/refuge.

3. Economic Viability

The economic feasibility of RFS is a key reason for its growing adoption among farmers. Studies show that RFS generally offers greater profitability compared to conventional rice monoculture, bolstered by diversified income streams, reduced input costs, and efficient resource utilization.

3.1. Diversified Income Streams

RFS allows farmers to generate multiple revenue sources from the same area. Alongside rice harvests, income from fish sales provides a buffer against market price fluctuations, thereby enhancing financial stability. For instance, when rice prices decline, steady fish prices help maintain profitability. Additionally, fish contribute essential protein to household diets, improving nutrition and lowering food expenses. Integration of other aquatic organisms, like prawns or snails, further broadens income potential.

3.2. Reduced Input Costs

RFS inherently promotes a more natural and less input-intensive farming approach, leading to substantial reductions in operational expenditures.

a. **Pest and Weed Control:** Omnivorous fish consume pests and aquatic weeds, reducing or eliminating the need for synthetic herbicides and pesticides, resulting in higher net profits.

b. **Fertilizer Reduction:** Fish waste provides essential nutrients that naturally fertilize the soil, decreasing reliance on synthetic fertilizers and associated costs.

c. **Labor Efficiency:** Though initial setup may require labour, RFS can streamline operations, as fish help manage weeds, reducing manual labour needs.

3.3. Enhanced Productivity and Resource Use Efficiency

RFS optimizes the use of land and water resources, leading to higher overall productivity per unit area.

a. **Higher Overall Yield:** While individual rice yields may be similar to high-input monoculture, the combined yield of rice and fish from RFS significantly increases the biological productivity of the land.

b. **Water Use Efficiency:** RFS maintains higher water levels efficiently; the same water supports both rice and fish, minimizing evaporation and improving soil moisture retention.

c. **Economic Returns:** Case studies from regions like Bangladesh, China, India, and Vietnam indicate that RFS offers a higher net return per hectare compared to rice monoculture. For example, research in Assam, India, found RFS to be 50-70% more profitable, with a superior benefit-cost ratio than traditional rice farming.

Table 8. Comparative Economic Analysis: Rice Monoculture vs. Rice-Fish System

Economic Metric	Unit	Rice Monoculture (RM)	Rice-Fish System (RFS)	RFS Advantage
A. Gross Income	USD/ha	$3,000$	$4,500$	**$1,500$** (Fish sales)
B. Total Production Costs	USD/ha	$2,000$	$1,800$	**200** (Lower costs)
-- Breakdown of Costs:				
Fertilizer Cost	USD/ha	400	200	(Fish manure provides nutrients)
Pesticide Cost	USD/ha	250	50	(Fish act as natural pest controllers)
Seed/Fingerling Cost	USD/ha	150	250	(Higher cost due to fingerlings)
Labor & Water Mgt. Cost	USD/ha	800	900	(Slightly higher for trench/bund maintenance)
Other Fixed Costs	USD/ha	400	400	
C. Net Profit (A - B)	USD/ha	$1,000$	$2,700$	**$1,700$**
D. Benefit-Cost Ratio (BCR = A/B)	Unitless	1.50	2.50	**1.00**

4. Ecological Benefits

Beyond their economic advantages, RFS provides numerous ecological benefits that promote environmental sustainability and enhance agro-ecosystem health, especially in the face of global climate change and the need for eco-friendly farming practices.

4.1. Enhanced Soil Health and Nutrient Cycling

The presence and activities of fish within the paddy significantly improve soil physical, chemical, and biological properties.

a. **Nutrient Mobilization and Cycling:** Fish contribute to soil disturbance through their feeding and burrowing behaviours, which mobilize dormant nutrients, making them accessible to rice plants. Their excreta enrich the soil with organic matter and essential nutrients like nitrogen, phosphorus, and potassium, reducing the need for synthetic fertilizers and minimizing nutrient runoff and eutrophication.

b. **Soil Aeration:** Fish movement facilitates soil aeration, promoting microbial activity and influencing nutrient transformations, ultimately benefiting rice growth and soil structure.

c. **Microbial Activity:** The integrated paddy-fish environment supports a diverse microbial community, enhancing nutrient cycling, organic matter decomposition, and disease resistance.

4.2. Natural Pest and Weed Control

RFS functions as a sophisticated biological control system, significantly reducing the incidence of pests and weeds without chemical interventions.

a. **Pest Consumption:** Fish consume various rice pests, such as insect larvae and snails, lowering pest populations and minimizing the need for synthetic pesticides. This reduces harm to beneficial insects and non-target organisms.

b. **Weed Control:** Herbivorous and omnivorous fish help control aquatic weeds and algae, disrupting their growth and decreasing labor and chemical input for weed management.

c. **Disease Suppression:** A balanced agro-ecosystem enhances the natural resistance of rice plants to diseases and creates environments less conducive to pathogen proliferation.

4.3. Reduced Greenhouse Gas Emissions

Rice paddies, particularly under anaerobic flooded conditions, are a significant anthropogenic source of methane (CH_4), a potent greenhouse gas. RFS can play a role in mitigating these emissions.

a. **Methane Mitigation:** Fish movement and burrowing promote soil-water aeration, increasing oxygen levels that inhibit methanogenesis while promoting methane consumption. RFS can reduce CH_4 emissions by 10-30% compared to conventional practices.

b. **Nitrous Oxide (N_2O) Reduction:** The reduced dependence on synthetic nitrogen fertilizers also lowers N_2O emissions, a potent greenhouse gas released during excess nitrogen denitrification.

4.4. Biodiversity Conservation

RFS contributes significantly to the conservation and enhancement of agro-biodiversity.

a. **Increased Aquatic Biodiversity:** The integration of fish leads to a complex aquatic environment that supports diverse organisms, contributing to ecosystem resilience and stability.

b. **Habitat Creation:** Fish habitats create micro-habitats that benefit various amphibians, reptiles, and insects, further enriching local biodiversity.

c. **Ecosystem Services:** A diversified agro-ecosystem is better able to provide essential services, such as pollination, water purification, and nutrient cycling, all vital for long-term agricultural sustainability.

5. Operational Challenges

Despite the numerous benefits of RFS, its widespread adoption encounters several operational challenges that must be addressed for effective implementation.

5.1. Water Management Requirements

One of the most critical challenges in RFS is the need for precise and consistent water management.

a. **Water Depth and Retention:** RFS needs a stable water depth of 10-20 cm throughout the rice growing season, which is essential for fish health and growth.

- **b. Reliable Water Supply:** Erratic rainfall, droughts, or flooding can hinder RFS success by affecting water availability or leading to fish escape.
- **c. Infrastructure for Water Control:** Properly built bunds, inlets, and outlets are necessary for water flow regulation and preventing fish loss, requiring adequate resources and maintenance.

5.2. Conflict with Chemical Use

The fundamental principle of RFS, leveraging biological interactions, stands in direct conflict with the indiscriminate use of synthetic agrochemicals.

- **a. Pesticide Toxicity:** Conventional pesticides can harm fish, necessitating the adoption of organic or fish-safe alternatives that may not always be available or perceived as effective.
- **b. Fertilizer Management:** excessive use of nitrogenous fertilizers can cause algal blooms and oxygen depletion, negatively impacting fish health.

5.3. Initial Investment and Field Modifications

Setting up RFS involves significant capital and labour investments

- **a. Infrastructure Development:** Building or reinforcing structures for water control requires upfront costs that can be prohibitive for resource-poor farmers.
- **b. Training and Knowledge Acquisition:** Farmers need specialized knowledge in fish biology, water quality management, and integrated pest management, which may not be easily accessible.

5.4. Market Access and Value Chains

While RFS provides diversified products, challenges can arise in marketing and accessing efficient value chains for fish.

- **a. Market Infrastructure:** In many rural areas, infrastructure for transporting and selling live or fresh fish may be underdeveloped. Farmers might face issues with spoilage, price exploitation by intermediaries, or limited market access, especially for perishable fish products.
- **b. Processing and Storage:** Lack of appropriate processing, storage, and refrigeration facilities can further complicate market access and reduce the economic benefits from fish production.

[Table 3: Summary of Operational Challenges and Potential Mitigation Strategies]

This table would list each challenge, elaborate on its impact, and suggest practical solutions or mitigation strategies (e.g., drought-resistant fish species, farmer field schools, microfinance for infrastructure).

6. Policy Implications and Future Directions

The assessment of economic viability, ecological benefits, and operational challenges underscores the immense potential of RFS as a cornerstone of sustainable agriculture, but also highlights the need for concerted efforts to overcome existing barriers.

6.1. Policy Support

Government policies play a pivotal role in facilitating the widespread adoption of RFS. This includes:

- **a. Incentives and Subsidies:** Providing financial incentives, subsidies for infrastructure development (e.g., pond construction, bund reinforcement), and low-interest loans for initial investment can encourage farmers to transition to RFS.
- **b. Extension Services and Training:** Strengthening agricultural extension services to disseminate technical knowledge, conduct hands-on training programs, and establish farmer field schools focused on RFS best practices is crucial.
- **c. Research and Development:** Investing in research to develop more resilient rice and fish varieties, optimizing RFS designs for diverse agro-ecological zones, and identifying effective pest and disease management strategies is essential.
- **d. Market Development:** Policies supporting the development of efficient value chains for fish, including market infrastructure, cold storage facilities, and fair pricing mechanisms, will enhance the economic attractiveness of RFS.
- **e. Water Resource Management:** Integrated water resource management policies that ensure equitable and sustainable water allocation for RFS, especially in water-stressed regions, are vital.

6.2. Adaptive Management Strategies

Farmers and researchers must continuously adapt RFS practices to local conditions and emerging challenges.

a. **Climate Change Adaptation:** Developing RFS designs and management strategies that are resilient to climate change impacts, such as increased frequency of floods or droughts, is critical. This might involve cultivating flood-tolerant rice varieties and fish species, or designing refuge ponds that can sustain fish during prolonged dry spells.
b. **Species Diversification:** Exploring the integration of other indigenous aquatic organisms (e.g., local fish species, crabs, prawns, ducks) that are well-adapted to local conditions can further enhance biodiversity and diversify income sources.
c. **Organic and Biological Inputs:** Promoting the use of organic fertilizers, bio-pesticides, and other biological control methods to align with the eco-friendly nature of RFS.

7. Conclusion

The rice–fish farming system serves as an effective model for sustainable agricultural intensification, offering both enhanced economic returns through diverse outputs and reduced input costs for farmers. Additionally, it contributes significantly to ecological health by improving soil quality, controlling pests naturally, lowering greenhouse gas emissions, and fostering biodiversity, thereby supporting environmental sustainability and climate resilience. Despite its advantages, broader implementation faces challenges, including water management issues, conflicts with chemical usage, initial investment barriers, and a lack of specialized knowledge.

Addressing these challenges requires a comprehensive approach that includes strong policy support, targeted research and development, effective extension services, and adaptive management strategies. As the global community pursues food security and sustainability, rice-fish farming can transform from a niche practice into a widespread solution. This integrative method highlights the interconnectedness of aquaculture and agriculture, reflecting a holistic philosophy that champions ecological engineering in food production for a more sustainable and equitable agricultural future.

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Sustainable Integration of Aquaculture and Agriculture: Enhancing Food Security and Resource Efficiency

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1. Introduction

The global food system faces unprecedented challenges, driven by a burgeoning population, climate change, diminishing natural resources, and growing concerns about environmental degradation. Traditional agricultural and aquaculture practices, while crucial for feeding billions, often come with significant environmental footprints, including excessive water consumption, nutrient runoff, greenhouse gas emissions, and land degradation. As humanity strives to achieve the Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production), there is an urgent need for more resilient, efficient, and ecologically sound food production systems.

Integrated food systems, where two or more food production sectors are combined to create synergistic benefits, offer a promising pathway toward sustainability. Among these, the integration of aquaculture (the farming of aquatic organisms) and agriculture (the cultivation of crops and livestock) has garnered significant attention. This integration, often referred to as integrated aquaculture-agriculture (IAA) systems, aims to minimize waste, recycle nutrients, conserve water, and enhance overall productivity. By mimicking natural ecosystems, IAA systems seek to transform waste from one component into a valuable resource for another, thereby closing nutrient loops and reducing external inputs.

This article provides an in-depth analysis of the sustainable integration of aquaculture and agriculture. We will delve into the foundational principles, explore various established and emerging IAA models, and critically assess their potential to bolster food security and optimize resource efficiency. Furthermore, we will examine the economic viability, social acceptance, and environmental benefits and drawbacks of these systems, concluding with recommendations for policy, research, and implementation to foster their widespread adoption.

2. The Rationale for Integration: Addressing Global Challenges

The impetus for integrating aquaculture and agriculture stems from a recognition of the inherent inefficiencies and environmental costs associated with conventional food production.

a. **Water Scarcity:** Agriculture accounts for approximately 70% of global freshwater withdrawals. Traditional aquaculture, particularly pond-based systems, also requires substantial water resources. Integrated systems can significantly reduce water consumption through recirculation and nutrient recycling.

b. **Nutrient Pollution:** Runoff from agricultural fields laden with fertilizers and pesticides, as well as nutrient-rich wastewater from aquaculture operations, contributes to eutrophication of aquatic ecosystems, harming biodiversity and water quality. IAA systems aim to capture and reuse these nutrients.

c. **Land Use Efficiency:** With finite arable land, optimizing land use is crucial. Integrated systems can produce multiple crops and aquatic organisms on the same land footprint, increasing overall productivity per unit area.

d. **Climate Change Mitigation:** Reduced energy consumption for input production (fertilizers, feed) and enhanced carbon sequestration in certain integrated systems can contribute to mitigating climate change.

e. **Food Security and Diversification:** IAA systems can provide a diversified range of food products (fish, vegetables, fruits), enhancing nutritional security and offering resilience against market fluctuations or crop failures.

3. Typologies of Integrated Aquaculture-Agriculture Systems

Integrated aquaculture-agriculture systems are diverse, ranging from simple traditional practices to sophisticated modern technologies. These systems can be broadly categorized based on the degree of integration and the specific components involved.

3.1. Aquaponics

Aquaponics is a symbiotic system that combines conventional aquaculture (raising aquatic animals such as fish, snails, prawns, or crayfish in tanks) with hydroponics (cultivating plants in water) in a recirculating environment. The nutrient-rich effluent from the aquaculture component serves as a natural fertilizer for the hydroponic plants. In return, the plants absorb these nutrients, effectively filtering the water, which is then returned to the fish tanks. This mutually beneficial relationship reduces water usage and eliminates the need for external fertilizers for the plants.

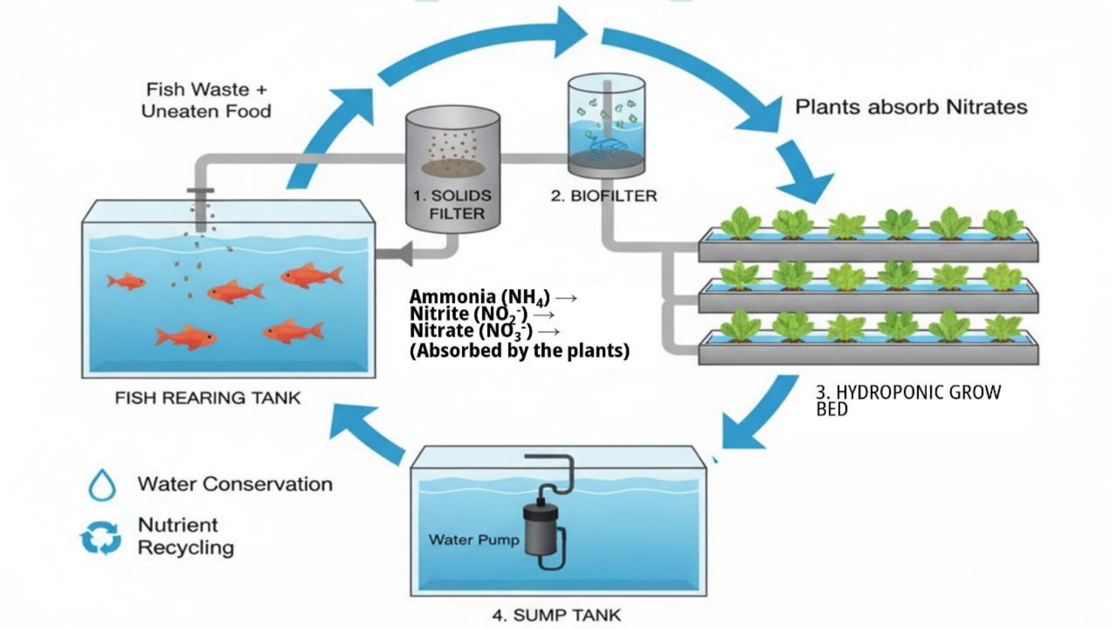

Figure 5. Conceptual Diagram of Aquaponics

Table 9. Key Aquaponic System Designs

Design Type	Description	Advantages	Disadvantages
Media Beds	Plants grown in inert media (e.g., clay pebbles, gravel) also filter water.	Excellent biofiltration; suitable for beginners; good for root crops.	It can be heavy; cleaning can be laborious; limited plant diversity.
Nutrient Film Technique (NFT)	A thin film of nutrient-rich water flows over plant roots in channels.	Water and nutrient efficient, easy harvesting, good for leafy greens.	Requires good water flow management; prone to blockages; limited root space.
Deep Water Culture (DWC) / Raft System	Plants floated on rafts directly on the water surface with roots submerged.	Excellent for leafy greens; simple to operate; scalable; good oxygenation.	Requires separate solids filtration; less suitable for heavy fruiting plants.
Vertical Aquaponics	Stacking plant growing layers vertically, often combined with NFT or DWC.	Maximizes space efficiency; higher yield per footprint.	It can be complex to manage water distribution, higher initial setup cost.

3.2. Aquamimicry

Aquamimicry is an emerging sustainable aquaculture approach that aims to mimic the natural conditions of a healthy shrimp or fish habitat. It focuses on developing a thriving microbial community (biofloc technology) and using probiotics to maintain water quality and enhance the health and growth of aquatic organisms, thereby reducing the need for water exchange and antibiotics. While not directly integrating crops, aquamimicry significantly reduces the environmental footprint of aquaculture, making it a valuable component for broader IAA systems. The nutrient-rich sludge from aquamimicry ponds, after proper treatment, can be used as organic fertilizer for crops.

Key Principles of Aquamimicry:

a. **Probiotic Application:** Regular introduction of beneficial bacteria to maintain water quality and suppress pathogens.
b. **Biofloc Development:** Encouraging the formation of biofloc (aggregates of bacteria, algae, protozoa, and organic matter), which acts as a natural food source and bioremediator.
c. **Minimal Water Exchange:** Reducing reliance on fresh water by maintaining water quality within the pond.
d. **Carbon-Nitrogen Ratio Management:** Maintaining an optimal C: N ratio to promote microbial growth and nutrient assimilation.

3.3. Integrated Multi-Trophic Aquaculture (IMTA)

IMTA is an approach where the by-products (wastes) from one species are recaptured and converted into fertilizers, feed, and energy for the co-cultured species. It involves cultivating multiple species from different trophic levels (e.g., fed aquaculture species like fish/shrimp, extractive organic aquaculture species like shellfish, and extractive inorganic aquaculture species like seaweed) in proximity. This creates a balanced system where waste from one component becomes a resource for another, enhancing environmental sustainability, economic stability, and social acceptability.

Table 10. Components and Functions in an IMTA System

Trophic Level	Example Species	Function in IMTA System	Output/Benefit
Fed Aquaculture	Finfish (e.g., salmon, tilapia), Shrimp	Primary production of marketable seafood generates dissolved/particulate waste.	High-value protein source.
Extractive Organic	Shellfish (e.g., mussels, oysters)	Filter feeders remove particulate organic matter (uneaten feed, feces).	Marketable shellfish; improved water clarity.
Extractive Inorganic	Seaweed (e.g., kelp, Gracilaria)	Absorbs dissolved inorganic nutrients (nitrogen, phosphorus).	Marketable seaweed (food, fertilizer, biofuel); improved water chemistry.
Deposit Feeders	Sea cucumbers, polychaetes	Consume particulate waste that settles on the seabed.	Marketable species; seabed remediation.

3.4. Rice-Fish Culture

Rice-fish culture is a traditional integrated farming system prevalent in many Asian countries. It involves cultivating fish in rice paddies, either simultaneously with rice or in rotation. Fish benefit from the food resources in the paddy (insects, weeds) and the protection provided by the rice plants, while they, in turn, control pests (weeds, insects), fertilize the rice through their excretions, and enhance soil aeration. This system reduces the need for pesticides and chemical fertilizers, improves rice yields, and provides an additional source of protein.

Key Benefits of Rice-Fish Systems:

a. **Pest Control:** Fish consume insect larvae and weeds, reducing the need for chemical pesticides.
b. **Fertilization:** Fish excretions provide nutrients for rice plants, reducing fertilizer requirements.
c. **Weed Control:** Fish consume weeds, reducing competition with rice.
d. **Aeration:** Fish activity helps aerate the soil.
e. **Increased Income:** Farmers gain two crops (rice and fish) from the same land, increasing their income and food security.

4. Benefits of Sustainable Integration

The widespread adoption of IAA systems offers a multitude of benefits across environmental, economic, and social dimensions.

4.1. Environmental Benefits

a. **Water Conservation:** Recirculating systems like aquaponics can cut water use by up to 90% versus conventional agriculture, while IMTA and rice-fish systems optimize water utilization.

b. **Nutrient Cycling and Pollution Reduction:** These systems capture and reuse waste nutrients, minimizing runoff and reducing eutrophication and algal blooms, effectively closing nutrient loops.

c. **Reduced Chemical Inputs:** Symbiotic relationships in IAA systems lessen the need for synthetic fertilizers, pesticides, and antibiotics, with fish in rice paddies controlling pests and bacteria in aquaponics, converting fish waste into nutrients.

d. **Biodiversity Enhancement:** Rice-fish systems improve biodiversity by providing habitats for various aquatic species, while IMTA systems promote a diverse marine environment.

e. **Carbon Footprint Reduction:** Localizing food production and decreasing reliance on energy-intensive external inputs can lower greenhouse gas emissions related to food production and transportation.

4.2. Economic Benefits

a. **Increased Productivity and Diversification:** Integrated systems enable farmers to produce various food products (fish, vegetables, rice, shellfish) from the same area, enhancing overall yields and creating diverse income streams, which helps mitigate market price fluctuations.

b. **Reduced Operating Costs:** By relying less on external inputs like fertilizers, pesticides, and feed, operating costs are lowered.

c. **Higher Product Value:** Sustainably produced products can fetch higher prices due to their organic nature, reduced chemical residues, and perceived environmental benefits.

d. **Job Creation:** The establishment and management of integrated systems generate employment opportunities, particularly in rural regions.

e. **Local Food Systems:** IAA systems promote local food production, bolstering local economies and decreasing dependence on vulnerable, lengthy supply chains.

4.3. Social Benefits

a. **Enhanced Food Security and Nutrition:** Producing diverse protein sources (fish) and nutrient-rich crops (vegetables, rice) improves food security and nutrition, particularly for vulnerable populations.

b. **Improved Livelihoods:** Smallholder farmers using IAA systems can achieve more stable incomes and an improved quality of life.

c. **Community Resilience:** Diversified local food production enhances community resilience against climate change, economic crises, and disruptions in global supply chains.

d. **Education and Awareness:** Integrated systems promote a better understanding of ecological principles, resource management, and sustainable food practices among farmers and consumers.

e. **Reduced Health Risks:** Lower pesticide and antibiotic use results in safer food products and decreases the risk of antibiotic-resistant bacteria development.

5. Challenges and Limitations

Despite the numerous advantages, the widespread adoption of IAA systems faces several challenges.

a. **Initial Investment Costs:** High capital requirements for infrastructure can hinder smallholder farmers.

b. **Technical Knowledge and Management Complexity:** Requires expertise in various fields, making system imbalances difficult to manage.

c. **Disease Management:** Outbreaks in one component can affect others, necessitating stringent biosecurity.

d. **Market Access and Consumer Acceptance:** Niche products may struggle with market access and consumer awareness.

e. **Regulatory Frameworks:** Fragmented regulations for agriculture and aquaculture complicate the approval process for integrated systems.

f. **Geographic and Climatic Constraints:** Suitability is affected by climate and geographical factors, such as freshwater availability.

g. **Scale-Up Challenges:** Expanding to large operations can introduce new complexities and inefficiencies.

6. Best Practices and Implementation Strategies

To overcome these challenges and facilitate the successful implementation of sustainable IAA systems, several best practices and strategies are recommended.

a. **Pilot Projects and Research:** Invest in R&D to optimize designs and species combinations, demonstrating feasibility through pilot projects.

b. **Training and Capacity Building:** Implement comprehensive training programs for farmers and technicians to enhance technical and management skills.

c. **Financial Incentives and Support:** Provide subsidies, grants, and low-interest loans to ease initial investment costs for farmers adopting IAA systems.

d. **Policy and Regulatory Reforms:** Create supportive policies and streamlined regulations specifically for integrated food systems.

e. **Market Development and Value Chains:** Enhance direct market access, promote sustainable product attributes, and educate consumers on benefits.

f. **Modular and Adaptable Designs:** Develop flexible system designs that can be customized to local conditions and farmer capabilities.

g. **Disease Prevention and Biosecurity:** Implement rigorous biosecurity measures and health management strategies to mitigate disease risks.

h. **Community-Based Approaches:** Foster community engagement and collective actions in planning and managing IAA systems for shared learning and support.

7. Future Directions and Research Needs

The field of integrated aquaculture-agriculture is dynamic, with significant scope for innovation and improvement. Future research should focus on:

a. **Species Optimization:** Identify compatible fish and plant species, including indigenous varieties, to enhance growth and nutrient cycling in integrated systems.

b. **Advanced Sensor Technology and Automation:** Utilize IoT sensors, AI, and automation for real-time monitoring and control of water quality and nutrient levels, improving efficiency and reducing labour needs.

c. **Waste Valorisation:** Research the complete valorisation of waste streams (e.g., fish sludge for biofertilizers, unused plant biomass for compost or animal feed) to create zero-waste systems.

d. **Energy Efficiency and Renewable Energy Integration:** Design energy-efficient IAA systems that utilize renewable energy sources (solar, wind) to lower operational costs and environmental impact.

e. **Economic Modeling and Risk Assessment:** Develop economic models to evaluate the long-term profitability and financial risks of diverse IAA systems across varying scales and locations.

f. **Climate Resilience:** Explore ways to enhance the resilience of integrated systems to climate change-related impacts, including extreme weather and water availability changes.

g. **Social and Cultural Acceptance:** Investigate social and cultural factors affecting the adoption of IAA systems, emphasizing traditional knowledge, consumer perceptions, and community engagement.

h. **Nutrient Dynamics and Microbial Ecology:** Enhance understanding of nutrient dynamics and microbial communities within integrated systems to optimize efficiency and stability.

8. Conclusion

The sustainable integration of aquaculture and agriculture represents a powerful paradigm shift in food production, offering a compelling solution to many of the challenges facing our global food system. Systems like aquaponics, aquamimicry, IMTA, and rice-fish culture exemplify how ecological principles can be harnessed to create more efficient, resilient, and environmentally sound pathways to food security.

By minimizing waste, conserving water, recycling nutrients, and reducing reliance on external chemical inputs, IAA systems not only mitigate environmental degradation but also enhance productivity, diversify income, and improve livelihoods. While challenges related to initial investment, technical expertise, and regulatory frameworks exist, these can be addressed through targeted research, capacity building, supportive policies, and financial incentives.

Embracing the holistic and synergistic nature of integrated food systems is not merely an option but a necessity for building a future where food is abundant, nutritious, and produced in harmony with our planet. Continued innovation, collaboration, and a commitment to sustainability will unlock the full potential of these integrated approaches, paving the way for a more food-secure and resource-efficient world.

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Remote Sensing and GIS-Based Soil Texture Mapping for Precision Land Management

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1. Introduction

Precision land management has emerged as a key component of sustainable agriculture, emphasizing the importance of understanding and managing spatial variability within agricultural fields. A critical aspect of this practice is the accurate acquisition of information regarding soil properties, particularly soil texture, which encompasses the relative proportions of sand, silt, and clay. Soil texture profoundly influences essential soil characteristics, including hydraulic properties that govern water retention and movement, cation exchange capacity affecting nutrient availability, and overall nutrient retention capabilities. Variations in soil texture can result in heterogeneous growing conditions, leading to differential crop growth and varying rates of nutrient leaching, which necessitate detailed soil texture maps. Such maps are crucial for informed decision-making in irrigation scheduling, determining optimal fertilizer application rates, and selecting crop varieties suitable for specific field zones.

To address the limitations of traditional soil sampling and laboratory analysis methods, which can be labor-intensive and costly, the agricultural sector is increasingly leveraging advanced technologies such as remote sensing and Geographic Information Systems (GIS). Remote sensing utilizes satellite imagery, aerial photography, and sensor data to provide a comprehensive view of soil properties over extensive areas, enabling rapid and cost-effective assessments of spatial variability. Meanwhile, GIS facilitates the integration and analysis of this spatial data, aiding in the creation of high-resolution soil texture maps. These technological advancements empower farmers and agronomists to make data-driven decisions that enhance crop management, optimize resource use, and minimize environmental impacts. As remote sensing and GIS technologies continue to evolve, their integration into precision agriculture promises to transform farming practices, resonating with the need for efficient and sustainable solutions to address global agricultural challenges.

2. Principles of Remote Sensing for Soil Texture Assessment

Remote sensing involves acquiring information about Earth's surface without direct contact. For soil texture mapping, this typically involves analyzing electromagnetic radiation reflected or emitted from the soil surface. Different soil constituents and properties interact uniquely with various wavelengths, allowing for their differentiation.

2.1. Spectral Reflectance Characteristics of Soil

The spectral reflectance of soil is influenced by several factors, including organic matter content, moisture content, iron oxides, and critically, soil texture (Stoner & Baumgardner, 1981).

- **a. Sand:** Sandy soils are primarily composed of quartz, which accounts for their high reflectance across the visible and near-infrared (NIR) spectrum. Because of the larger particle size associated with sand, these soils often display a relatively flat spectral curve, indicating consistent reflectance across various wavelengths. This characteristic leads to a lighter appearance and lower moisture retention compared to finer soil types.
- **b. Silt:** Silty soils, consisting of intermediate-sized particles, exhibit reflectance values that lie between those of sand and clay. Their unique texture allows for better moisture retention than sand, while still reflecting lighter than clay soils. The spectral signature of silt shows moderate variability, responding to changes in organic matter and moisture content.
- **c. Clay:** Clay minerals, with their smaller particle size and significantly higher surface area, absorb more radiation, resulting in markedly lower reflectance, especially in the NIR region. The finer texture of clay not only reduces light reflectance but also enhances the potential for water adsorption. The presence of water molecules bound to clay particles further diminishes reflectance values, resulting in a spectral

profile that is distinct from both sand and silt. This property of clay can affect soil moisture dynamics and nutrient availability, influencing agricultural and environmental processes.

2.2. Remote Sensing Platforms and Sensors

Various remote sensing platforms and sensors are employed for soil texture mapping, each offering different spatial, spectral, and temporal resolutions.

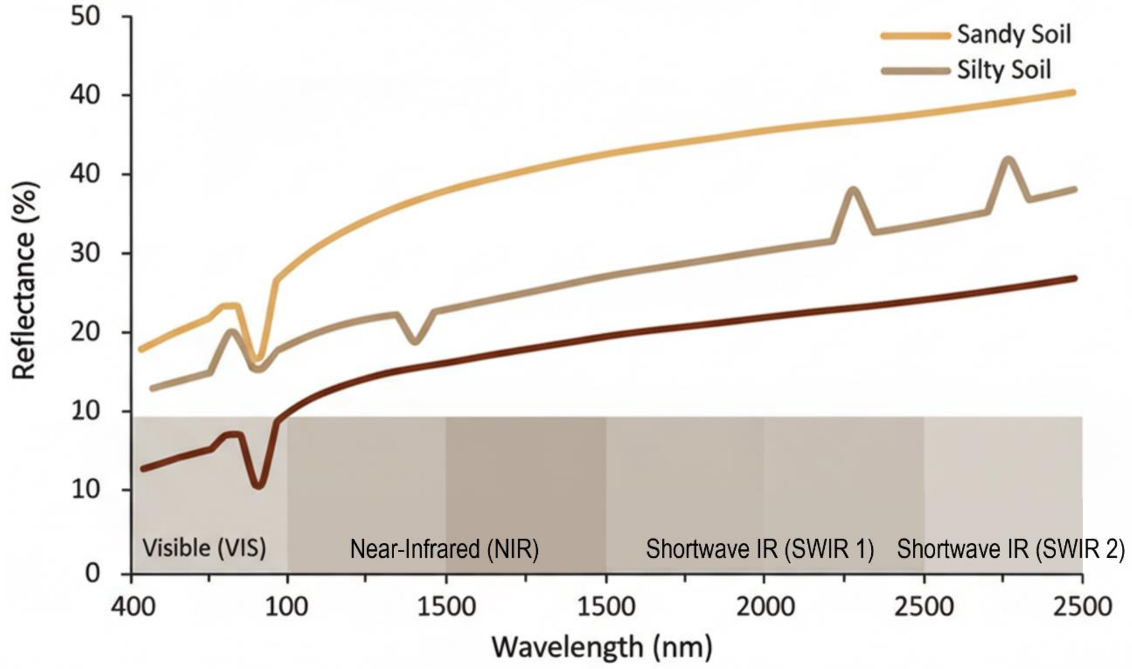

Figure 1. Generalized Spectral Reflectance Curves for Different Soil Textures

Table 11. Common Remote Sensing Platforms for Soil Studies

Platform/Sensor	Resolution (Spatial)	Key Spectral Bands	Advantages	Limitations
Landsat (OLI, TM)	30 m	Visible, NIR, SWIR	Free data, long archive, global coverage	Moderate spatial resolution
Sentinel-2 (MSI)	10-20 m	Visible, Red Edge, NIR, SWIR	High spatial resolution, frequent revisit	Cloud cover can be an issue
MODIS	250-1000 m	Visible, NIR, SWIR	High temporal resolution, global coverage	Low spatial resolution
Hyperspectral (e.g., AVIRIS, PRISMA)	Variable (e.g., 2-20 m)	Hundreds of narrow bands	Detailed spectral information, improved discrimination	High cost, data processing complexity
UAV-based sensors	Centimeter-level	Visible, NIR, Red Edge	Very high spatial resolution, on-demand	Limited coverage area, weather-dependent

3. Integration with Geographic Information Systems (GIS)

The effective translation of raw remote sensing data into actionable soil texture maps for precision land management relies fundamentally on the analytical power of Geographic Information Systems (GIS). GIS is not merely a mapping tool; it is a robust computational framework designed for capturing, storing, analyzing, and managing spatially referenced data. The integration process is what transforms spectral values into spatial intelligence.

3.1. Data Integration and Spatial Database Management

GIS provides the spatial database environment necessary to bring together disparate data types, each with its unique projection, scale, and format, into a common coordinate system.

a. **Remote Sensing Layers:** Corrected satellite imagery (e.g., spectral bands, calculated indices) forms the foundational raster layers.
b. **Ground Truth Data:** Georeferenced soil sampling points, which are vector data (points), are stored with their attribute data (laboratory measurements of sand, silt, and clay percentages).
c. **Ancillary Spatial Data:** Essential environmental covariates are integrated as raster or vector layers. This includes:
   i. **Digital Elevation Models (DEMs):** Used to derive topographic attributes such as slope, aspect, curvature, and the Topographic Wetness Index (TWI). These variables are proxies for long-term processes of soil formation and material redistribution, which strongly correlate with soil texture.
   ii. **Geological and Hydrological Maps:** Provide context on parent material and water flow patterns.

3.2. Geostatistical and Spatial Analysis

GIS is essential for performing the advanced spatial analyses required to create continuous soil texture maps from discrete sampling points and continuous spectral/topographic data.

a. **Interpolation:** Techniques such as Kriging or Inverse Distance Weighting (IDW) are used within the GIS to estimate soil properties at unsampled locations based on the ground truth points. However, in the remote sensing context, interpolation is often used to spatially model the residuals of the machine learning predictions, improving local accuracy.
b. **Zonal Statistics and Overlay Analysis:** GIS tools are used to extract the values of all co-variate layers (spectral indices, topographic attributes) corresponding to each ground truth sample point. This forms the training dataset for the subsequent statistical and machine learning models.
c. **Terrain Analysis:** Algorithms are applied to the DEM to generate the topographic co-variates (e.g., TWI, stream power index), which serve as crucial predictive variables in Digital Soil Mapping (DSM) models.

3.3. Predictive Modeling and Spatial Prediction

The core function of GIS in this step is to serve as the platform for applying the trained machine learning model (e.g., Random Forest, PLSR) across the entire study area.

a. **Model Training:** The integrated data (vector ground truth attributes + extracted raster co-variate values) is exported for external statistical software or integrated GIS-based machine learning toolboxes.
b. **Model Application (Prediction):** The trained model is re-imported and run within the GIS environment, which applies the derived mathematical relationship to every pixel based on its specific covariate values. This process generates a continuous, high-resolution prediction raster for each target soil property (sand, silt, and clay percentage).

3.4. Classification and Visualization for Decision Support

Finally, the GIS environment transforms the quantitative prediction rasters into qualitative, decision-support maps.

a. **Textural Classification:** The predicted percentage maps of sand, silt, and clay are combined and classified according to a standard system (e.g., USDA Soil Textural Triangle) to delineate discrete soil textural classes (e.g., Sandy Loam, Clay). This is often done using a custom spatial model or script within the GIS.
b. **Thematic Mapping:** The resulting soil texture map is overlaid with other relevant information (e.g., roads, field boundaries, existing yield maps) to create a comprehensive thematic map. This map is the direct input for Variable Rate Technology (VRT) applications, allowing agricultural machinery to adjust inputs based on the defined management zones. The spatial accuracy and visual clarity of this final output are paramount for effective decision-making at the field level.

4. Methodology for Remote Sensing and GIS-Based Soil Texture Mapping

A typical workflow for remote sensing and GIS-based soil texture mapping involves several key steps:

4.1. Data Acquisition and Pre-processing

a. **Remote Sensing Imagery:** Selection and acquisition of appropriate satellite or aerial imagery. Pre-processing involves radiometric calibration, atmospheric correction, and geometric correction to ensure accurate reflectance values and spatial alignment.

b. **Ground Truth Data:** Collection of georeferenced soil samples from the study area. These samples are analyzed in the laboratory to determine their sand, silt, and clay percentages. This ground truth data is crucial for model calibration and validation.

c. **Ancillary Data:** Gathering additional spatial data layers such as DEMs (from which slope, aspect, and topographic wetness index can be derived), land cover maps, and geological maps.

4.2. Feature Extraction from Remote Sensing Data

a. **Spectral Indices:** Calculation of various spectral indices that are sensitive to soil properties. Examples include:

- **Brightness Index (BI):** Reflects overall soil brightness, often inversely related to organic matter and clay content.
- **Clay Index (CI):** Designed to highlight clay absorption features.
- **Soil Moisture Index (SMI):** Sensitive to soil water content, which can indirectly relate to texture.

b. **Principal Component Analysis (PCA):** A dimensionality reduction technique that transforms original spectral bands into a new set of uncorrelated components, often separating spectral information related to soil components from other noise.

4.3. Statistical and Machine Learning Modeling

The relationship between remote sensing features (spectral bands, indices, topographic derivatives) and ground truth soil texture data is established using various modeling techniques.

a. **Regression Models:** Multiple Linear Regression (MLR), Partial Least Squares Regression (PLSR) can be used to predict sand, silt, and clay percentages.

b. **Machine Learning Algorithms:** More advanced techniques often yield superior results due to their ability to capture non-linear relationships.

- **Random Forest (RF):** An ensemble learning method that builds multiple decision trees and averages their predictions.
- **Support Vector Machines (SVM):** A supervised learning model with associated learning algorithms that analyze data for classification and regression analysis.
- **Artificial Neural Networks (ANN):** Inspired by the human brain, these algorithms can learn complex patterns in data.
- **Gradient Boosting Machines (GBM):** Builds an ensemble of weak prediction models, typically decision trees.

4.4. Model Validation and Mapping

a. The developed model is validated using a separate set of ground truth data (validation set) to assess its accuracy (e.g., R-squared, Root Mean Square Error - RMSE).

b. Once validated, the model is applied to the entire remote sensing image to generate continuous maps of sand, silt, and clay percentages. These can then be classified into standard soil textural classes (e.g., sandy loam, clay loam) using the USDA or FAO textural triangles.

5. Advantages and Limitations

5.1. Advantages:

a. **Cost-Effectiveness:** Reduces the need for extensive field sampling and laboratory analysis over large areas.

b. **Spatial Coverage:** Enables mapping of soil texture across vast and often inaccessible regions.

c. **High Resolution:** Provides spatially continuous maps, revealing within-field variability not captured by traditional methods.

d. **Timeliness:** Allows for rapid assessment and updates, supporting dynamic decision-making.
e. **Integration:** Seamlessly integrates with other spatial datasets for comprehensive land management planning.

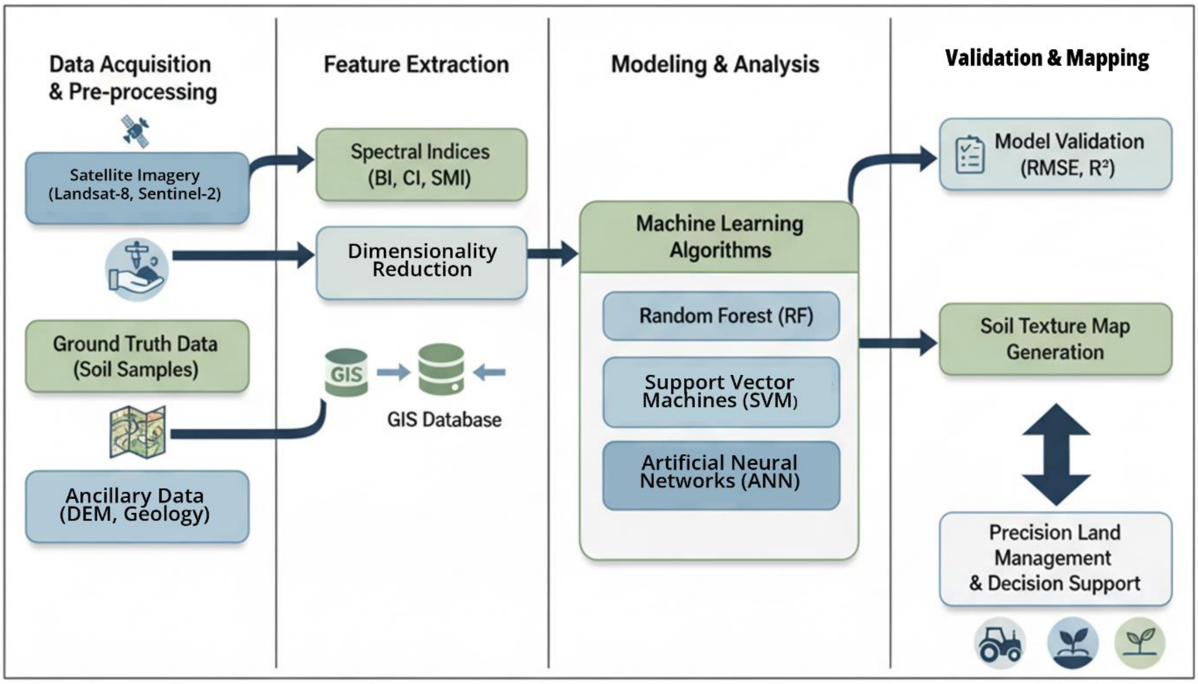

Figure 2. Conceptual Workflow for Remote Sensing and GIS-Based Soil Texture Mapping

5.2. Limitations:

a. **Ground Cover:** Dense vegetation cover significantly interferes with direct soil spectral sensing, requiring methods for bare soil pixel extraction or using radar data.
b. **Soil Moisture:** Variations in soil moisture content can mask or alter spectral signatures of soil texture.
c. **Surface Roughness:** Tillage practices and surface roughness can influence spectral reflectance.
d. **Calibration Data:** The accuracy of the models heavily depends on the quality and spatial distribution of ground truth data.
e. **Complexity:** Requires expertise in remote sensing, GIS, and statistical/machine learning techniques.

6. Applications in Precision Land Management

Accurate soil texture maps derived from remote sensing and GIS are invaluable for various precision land management applications:

a. **Variable Rate Irrigation (VRI):** Delineating zones with different water holding capacities to apply water efficiently and prevent over- or under-irrigation.
b. **Variable Rate Fertilization:** Tailoring nutrient application based on soil textural zones, optimizing nutrient uptake and minimizing environmental pollution from nutrient runoff.
c. **Crop Selection and Zoning:** Identifying areas suitable for specific crops that thrive in particular soil textural conditions.
d. **Tillage Management:** Adapting tillage intensity and implement selection to different soil textures to improve soil structure and reduce compaction.
e. **Soil Health Monitoring:** Serving as a baseline for monitoring changes in soil properties over time, indicating the effectiveness of management practices.

7. Future Directions

The field of remote sensing and GIS for soil texture mapping is continually evolving. Future advancements include:

a. Hyperspectral Remote Sensing: The increasing availability of hyperspectral data will allow for more precise characterization of soil mineralogy and texture due to its high spectral resolution.

b. Radar and Lidar Integration: Active sensors like Synthetic Aperture Radar (SAR) can penetrate vegetation and provide information on soil moisture and roughness, while Lidar can refine topographic derivatives.

c. Deep Learning: Advanced deep learning architectures (e.g., Convolutional Neural Networks) are showing promise in extracting complex features from multi-source remote sensing data for improved accuracy.

d. Data Fusion: Integrating data from multiple platforms (satellite, UAV, ground sensors) at different scales to create more comprehensive and robust soil property maps.

e. Cloud-Based Processing: Utilizing cloud computing platforms (e.g., Google Earth Engine) for efficient processing of large datasets and model deployment, making these technologies more accessible.

8. Conclusion

Remote sensing and GIS offer a transformative approach to soil texture mapping, moving beyond the limitations of traditional methods. By leveraging the spectral characteristics of soil and the analytical capabilities of GIS, agricultural practitioners can acquire detailed and spatially explicit information about soil texture. This information is fundamental for implementing effective precision land management strategies, leading to optimized resource use, enhanced crop productivity, reduced environmental impact, and ultimately, a more sustainable agricultural future. As technology continues to advance, the accuracy, efficiency, and accessibility of these tools will further improve, solidifying their role as indispensable components of modern agricultural decision-making.

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Utilizing Agricultural Waste for Sustainable Aquafeed Production: Innovations Toward a Circular Bioeconomy

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1. Introduction

Global aquaculture production has witnessed exponential growth over the past few decades, surpassing wild-capture fisheries as the primary source of seafood for human consumption (FAO, 2022). This expansion is driven by increasing global population, rising demand for protein, and the declining productivity of many wild fish stocks. However, the sustainability of this growth trajectory is increasingly scrutinized, particularly concerning aquafeed production.

Aquafeeds typically constitute the largest operational cost in aquaculture, often ranging from 40% to 70% of total production expenses. Historically, fishmeal and fish oil, derived from wild-caught forage fish, have been indispensable ingredients due to their superior nutritional profiles, including high protein content, essential amino acids, and omega-3 fatty acids. Nevertheless, the finite nature of marine resources and concerns about their ecological impact necessitate a paradigm shift towards more sustainable and environmentally friendly feed ingredients (Naylor *et al*., 2009).

Simultaneously, the agricultural sector is a major producer of waste materials, including crop residues, food processing byproducts, and animal manures. These wastes often accumulate in landfills or are disposed of through burning, leading to environmental pollution, greenhouse gas emissions, and resource depletion. The concept of a "circular bioeconomy" offers a compelling solution, advocating for the valorisation of these biological wastes into valuable products, thus minimizing waste and maximizing resource efficiency (Kircher & Jagemann, 2020). This article focuses on the intersection of these two critical sectors, exploring the potential of agricultural waste as a sustainable and economically viable resource for aquafeed production.

2. The Imperative for Sustainable Aquafeed

The reliance on marine ingredients in aquafeeds presents several sustainability challenges:

a. **Overexploitation of Forage Fish:** The demand for fishmeal and fish oil exerts immense pressure on wild forage fish stocks, impacting marine food webs and the livelihoods of artisanal fishing communities (Pauly *et al*., 1998).
b. **Environmental Footprint:** The carbon footprint associated with harvesting, processing, and transporting marine ingredients is substantial.
c. **Price Volatility:** The fluctuating supply and demand of fishmeal and fish oil lead to significant price volatility, impacting the economic stability of aquaculture operations.
d. **Contaminant Accumulation:** Marine ingredients can sometimes accumulate heavy metals and persistent organic pollutants, posing food safety concerns for farmed aquatic species and ultimately for human consumers.

3. Agricultural Waste Streams: A Resource for Aquafeed

Agricultural waste encompasses a diverse range of materials, each with unique nutritional and physicochemical properties. Effective utilization requires appropriate processing technologies to enhance digestibility, remove anti-nutritional factors, and concentrate valuable nutrients. Table 1 provides an overview of common agricultural waste streams and their potential as aquafeed ingredients.

Table 12. Common Agricultural Waste Streams and Their Potential as Aquafeed Ingredients

Agricultural Waste Stream	Examples	Key Nutritional Components	Potential Aquafeed Application
Crop Residues	Rice straw, wheat bran, corn stover, bagasse, cassava peel	Lignocellulose, carbohydrates, residual protein, minerals	Fiber source, substrate for microbial protein, energy source
Food Processing Byproducts	Fruit pomace (grape, apple, citrus), vegetable waste, oilseed meals (soybean, sunflower, canola, palm kernel meal), brewers' spent grain	Sugars, pectin, fibre, residual protein, antioxidants, vitamins, minerals	Protein source, energy source, functional ingredients
Animal Manures	Poultry litter, pig manure, cattle dung	Nitrogen, phosphorus, organic matter, and undigested feed	Substrate for insect farming, algal production
Aquaculture Sludge	Fish faeces, uneaten feed	Protein, lipids, minerals, and organic matter	Nutrient recycling, substrate for microbial growth
Agro-industrial Byproducts	Molasses, whey, glycerol	Sugars, lactose, glycerol	Energy source, fermentation substrate

Source: Adapted from various literature reviews (e.g., Wang et al., 2017; Gasco et al., 2018).

4. Bioprocessing Technologies for Waste Valorisation

Transforming raw agricultural waste into suitable aquafeed ingredients often requires various bioprocessing technologies. These technologies aim to enhance nutrient availability, detoxify harmful compounds, and improve palatability. Figure 1 illustrates a general framework for valorizing agricultural waste into aquafeed ingredients. The main bioprocessing technologies include:

4.1. Chemical and Physicochemical Treatments

These methods involve using chemicals or physical forces to break down complex molecules, reduce anti-nutritional factors, and improve digestibility.

a. **Alkaline/Acid Hydrolysis:** Treatment with acids or bases can break down lignocellulosic biomass, making cellulose and hemicellulose more accessible for enzymatic degradation or direct utilization.

b. **Extrusion:** High temperature, pressure, and shear forces during extrusion can gelatinize starches, denature proteins, and inactivate anti-nutritional factors, improving digestibility and palatability of ingredients (Gasco *et al*., 2018).

c. **Micronization:** Grinding materials to a fine particle size can increase surface area, improving enzymatic activity and nutrient absorption.

4.2. Biological Treatments

Biological methods harness microorganisms or insects to convert waste into valuable biomass or enhance nutrient profiles.

a. **Fermentation (Microbial/Fungal):** Microorganisms such as yeast (e.g., *Saccharomyces cerevisiae*) or fungi (e.g., *Aspergillus niger*) can grow on agricultural waste substrates, converting complex carbohydrates into microbial protein, enzymes, and other bioactive compounds (Gram *et al*., 2017). This process can also reduce anti-nutritional factors and improve the amino acid profile of the substrate.

b. **Insect Farming (Bioconversion):** Insects like black soldier fly larvae (*Hermetia illucens*) can efficiently bioconvert various organic wastes (including crop residues, fruit and vegetable waste, and even manures) into high-protein and high-lipid biomass (Spranghers *et al*., 2017). The resulting insect meal and oil are promising alternatives to fishmeal and fish oil in aquafeeds.

c. **Algal Cultivation:** Microalgae and macroalgae can be cultivated using agricultural wastewater or nutrient-rich effluents, sequestering nutrients and producing biomass rich in protein, lipids (including omega-3 fatty acids), and pigments (Bhuyar *et al*., 2021). This approach not only produces valuable feed ingredients but also contributes to wastewater treatment.

4.3. Enzymatic Hydrolysis

Enzymes are highly specific catalysts that can break down complex macromolecules into simpler, more digestible forms.

a. **Cellulases and Hemicellulases:** These enzymes break down cellulose and hemicellulose in lignocellulosic biomass, releasing fermentable sugars that can be used for microbial protein production or directly as energy sources.
b. **Proteases:** Proteases hydrolyze proteins into peptides and amino acids, improving protein digestibility and bioavailability. This is particularly useful for byproducts with less digestible protein.
c. **Lipases:** Lipases can break down lipids, potentially making them more accessible for absorption or modifying their fatty acid profiles.

5. Promising Agricultural Waste-Derived Aquafeed Ingredients

Several types of agricultural waste, when appropriately processed, hold significant promise as aquafeed ingredients:

5.1. Fermented Plant Proteins

Plant-based protein sources, such as soybean meal, canola meal, and sunflower meal, are already widely used in aquafeeds. However, they often contain anti-nutritional factors (e.g., phytate, trypsin inhibitors) and have a less balanced amino acid profile compared to fishmeal. Fermentation can effectively address these limitations. For instance, fermented soybean meal has shown improved digestibility and growth performance in various aquaculture species (Kishore *et al*., 2016).

5.2. Insect Meals and Oils

Insect meals, particularly from black soldier fly larvae (BSFL), are gaining traction as sustainable alternatives to fishmeal. BSFL meal typically contains 40-60% protein and 15-30% fat, with a good amino acid profile comparable to fishmeal. BSFL oil is also rich in lauric acid and can substitute for fish oil in certain applications (Gasco *et al*., 2019). Studies have demonstrated successful inclusion of BSFL meal in diets for salmonids, tilapia, shrimp, and other species, often without compromising growth or feed efficiency.

5.3. Algal Biomass

Microalgae (e.g., Spirulina, Chlorella, Schizochytrium) and macroalgae (seaweeds) are excellent sources of protein, lipids (especially omega-3 fatty acids like DHA and EPA), vitamins, and minerals. Their cultivation can be integrated with agricultural waste streams for nutrient recovery. Algal biomass can enhance growth, immune response, and pigmentation in aquatic animals (Ghasemi *et al*., 2017).

5.4. Single Cell Proteins (SCPs)

SCPs refer to the protein-rich biomass of microorganisms (bacteria, yeast, fungi) grown on various substrates, including agricultural waste and industrial byproducts. Yeast (e.g., Saccharomyces cerevisiae) and bacterial meals (e.g., Methylococcus capsulatus) are being explored as high-quality protein sources for aquafeeds due to their high protein content, balanced amino acid profile, and fast growth rates (Glencross *et al*., 2020).

5.5. Biofloc Biomass

Biofloc technology (BFT) is a sustainable aquaculture system where microbial communities (biofloc) convert waste nutrients (uneaten feed, faeces) into microbial biomass. This biomass serves as a natural feed supplement for the cultured animals, reducing the need for external feed inputs. Biofloc is rich in protein, lipids, and beneficial microorganisms, contributing to improved water quality and animal health (Crab *et al*., 2012).

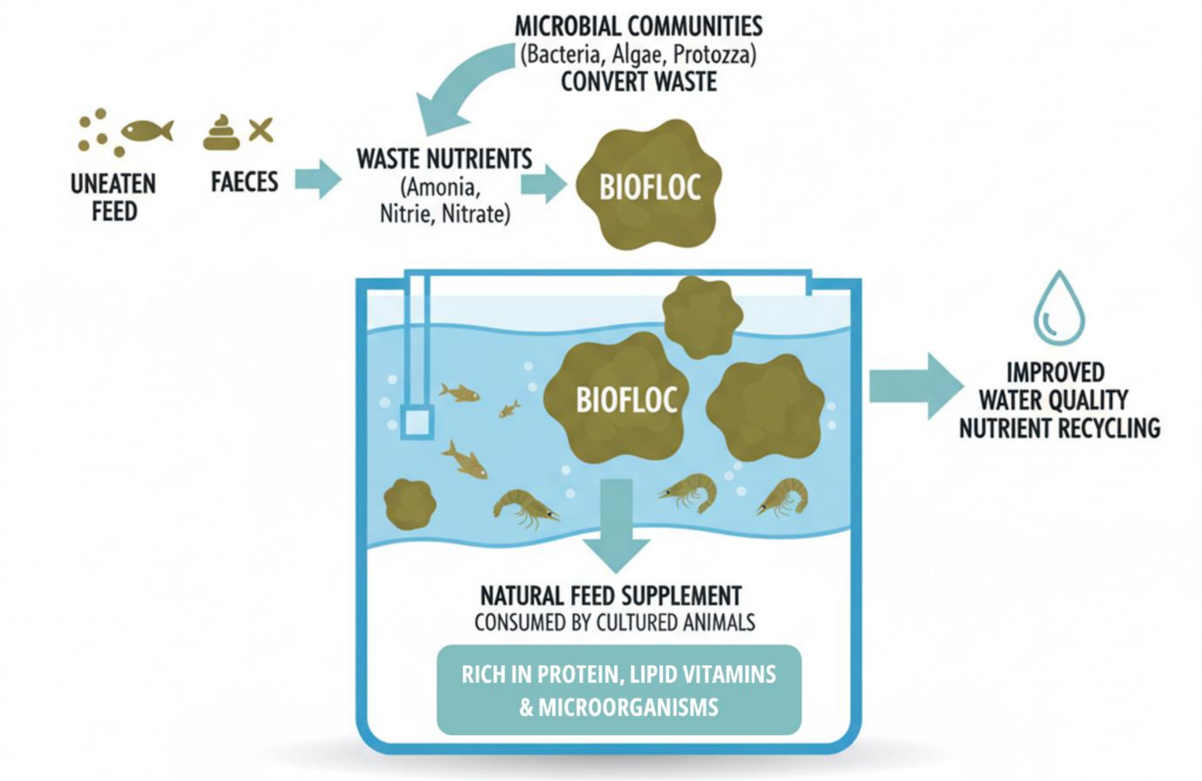

Figure 6. Biofloc Technology System (Adapted from Crab *et al.*, 2012)

6. Challenges and Considerations

Despite the significant potential, several challenges need to be addressed for the widespread adoption of agricultural waste-derived aquafeed ingredients:

a. **Nutritional Consistency and Quality Control:** The nutritional composition of agricultural waste can vary significantly depending on source, season, and processing methods. Ensuring consistent quality and preventing the accumulation of contaminants (e.g., pesticides, heavy metals, mycotoxins) is crucial.

b. **Anti-nutritional Factors:** Many agricultural byproducts contain anti-nutritional factors that can impair digestibility and nutrient utilization in aquatic animals. Effective processing technologies are required to mitigate these effects.

c. **Palatability and Digestibility:** Novel ingredients must be palatable and digestible for target aquaculture species. Acceptability trials and optimizing inclusion levels are essential.

d. **Regulatory Frameworks:** Clear regulatory guidelines are needed for the use of novel ingredients derived from waste streams, particularly regarding safety and labelling.

e. **Cost-Effectiveness and Scalability:** The economic feasibility of producing these ingredients at a commercial scale, competing with established feed components, is a major factor. The cost of processing and transportation must be considered.

f. **Research and Development:** Further research is needed to optimize processing technologies, evaluate the long-term effects of novel ingredients on growth, health, and product quality of various aquatic species, and develop appropriate feed formulations.

7. Economic and Environmental Benefits: Towards a Circular Bioeconomy

The successful integration of agricultural waste into aquafeed production offers multifaceted benefits:

a. **Reduced Environmental Impact:**
   - **Decreased Pressure on Marine Resources:** Less reliance on fishmeal and fish oil protects wild fish stocks and marine ecosystems.
   - **Waste Reduction:** Diverting agricultural waste from landfills or burning reduces pollution and greenhouse gas emissions.

- **Nutrient Recycling:** Closing nutrient loops by returning nutrients from waste back into the food system.

b. Enhanced Economic Sustainability:

- **Cost Reduction:** Agricultural waste can be a cheaper raw material, reducing aquafeed production costs.
- **Value Addition:** Creating new value streams for agricultural byproducts, benefiting farmers and processors.
- **Stable Ingredient Supply:** Reducing dependence on volatile international markets for marine ingredients.

c. Improved Food Security:

- **Increased Aquaculture Productivity:** Sustainable feed sources support the continued growth of the aquaculture sector, contributing to global protein supply.
- **Diversification of Feed Sources:** Enhances the resilience of the aquafeed supply chain.

8. Conclusion and Future Directions

The utilization of agricultural waste for sustainable aquafeed production represents a promising pathway towards a more resilient and environmentally friendly aquaculture industry within the framework of a circular bioeconomy. Innovations in bioprocessing technologies, particularly biological treatments like insect farming and microbial fermentation, are transforming low-value waste into high-value feed ingredients.

Future research and development should focus on:

a. **Multi-omics Approaches:** Applying genomics, proteomics, and metabolomics to understand the effects of novel ingredients on aquatic animal nutrition, health, and disease resistance.

b. **Advanced Bioprocessing:** Developing more efficient, energy-saving, and environmentally benign bioprocessing technologies.

c. **Integrated Biorefineries:** Establishing integrated biorefinery concepts where multiple valuable products (e.g., feed ingredients, biofuels, biofertilizers) are extracted from agricultural waste, maximizing resource utilization and economic returns.

d. **Life Cycle Assessment (LCA):** Conducting comprehensive LCAs to quantify the environmental benefits and identify potential trade-offs of using these novel ingredients.

e. **Policy and Market Incentives:** Developing supportive policies, regulations, and market mechanisms to encourage the production and adoption of sustainable aquafeed ingredients.

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Major Pests and Diseases Affecting Rabi Castor: Identification and Management

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Castor (*Ricinus communis* L.), a member of the Euphorbiaceae family, is an important oilseed crop of great economic significance. Castor seeds contain about 41%–64% oil (Olivares et al., 2013), serving as a vital raw material for diverse industries such as agriculture, medicine, chemicals, and household products (Agyenim-Boateng et al., 2018). Globally, India is the leading producer of castor, accounting for nearly 70% of the cultivated area and 87% of total global production, followed by Brazil and China (FAO, 2020).

In India, castor is cultivated over approximately 1.02 million hectares, producing around 1.98 million tons annually, with an average yield of 1,900 kg/ha (INDIASTAT, 2022–23). The major castor-producing states include Gujarat, Rajasthan, Telangana, Andhra Pradesh, Karnataka, Tamil Nadu, and Odisha. In Telangana, the crop is grown on about 5,000 hectares, producing nearly 5,000 tons with an average productivity of 984 kg/ha.
However, castor cultivation faces major challenges from various pests and diseases, particularly lepidopteran pests that cause severe yield losses. Yield reductions during the *kharif* season range from 29.1% to 50.9%, while losses increase to 49.1%–58.5% during the *rabi* season (Lakshminarayana and Duraimurugan, 2014). Although India's productivity is higher than the global average, pests such as semilooper (*Achaea janata* L.), tobacco caterpillar (*Spodoptera litura* F.), capsule borer (*Conogethes punctiferalis* Guenée), and several sucking pests continue to pose serious threats to castor production.

Semilooper (*Achaea janata* L.)

The semilooper, active from August to January, is a reddish-brown moth with black hindwings marked by white bands. Females lay about 450 blue-green eggs on leaves, hatching in 2–5 days. The larvae feed aggressively, leaving only midribs and veins, and grow up to 70 mm, displaying greyish-brown bodies with side stripes and a black head with red markings.


Castor semilooper damage

Tobacco Caterpillar (*Spodoptera litura* F.)

Found in tropical and subtropical areas, it damages crops like tobacco, cotton, tomato, and crucifers. Females lay up to 300 eggs in clusters covered with brown hairs, hatching in 3–5 days. Young caterpillars scrape leaves, creating a papery look, while older ones cause complete defoliation.



***Spodoptera litura* egg mass** | **1st instar larva** | ***Spodoptera litura* larva damage**

Management:

- Natural enemie (*Snellenius maculipennis*) acts as larval parasite of semilooper whose cocoons may be seen attached to the ventral aspect of the posterior end of the host caterpillar. Avoid chemical spray when 1-2 larval parasitoids are observed per plant.
- Plucking of leaves harbouring egg masses / gregarious larvae and destroying.
- Install pheromone traps (4–8/acre) and bird perches (5–6/acre).
- Apply neem oil (Azadirectin 1500 ppm) at 5 ml/L for early instar larvae.
- Avoid chemical sprays when larval parasitoids (e.g., *Snellenius maculipennis*) are present.
- Use Thiodicarb (1.5 g/L), Profenophos (2 ml/L) (if <25% defoliation)
- Flubendiamide (0.2 ml/L), Spinosad (0.3 ml/L), or Chlorantraniliprole (0.3 ml/L) based on defoliation severity. (if >25% defoliation).

Shoot and Capsule Borer (Conogethes punctiferalis)

This pest, active from September to February, damages shoots and capsules. Larvae bore into shoots, causing frass at entry points and webbed capsules covered in dark excreta. The total life cycle spans 25–33 days, with three generations annually.

Management:

- Remove and destroy infested shoots and capsules.
- Begin spraying at inflorescence formation and repeat after 20 days.
- Use Profenophos (2 ml/L) or Novaluron (1 ml/L) for >10% capsule damage.

Leafhopper (*Empoasca flavescens* Fabr.)

Light green or greenish yellow nymphs and adults suck sap from undersurface of leaf. As a result, the margins of leaf turn pale initially, later become yellowish and cause hopperburn or drying of leaves and showing brown necrotic patches in severe cases. Plants lose vigor and yield is affected. Peak infestation is during November to January.


Leafhopper damage | **Severe hopper burn caused by leaf hopper**

Management:

- Spray Profenophos (2 ml/L), Acetamiprid (0.2 g/L), or Clothianidin (0.1 g/L) when curling symptoms appear.
- Apply sprays at 15-day intervals during severe infestations.

Thrips (*Scirtothrips dorsalis*)

In the early stages, terminal leaves develop a silvered appearance, followed by dull yellowish-green patches on the upper surface and brown necrotic spots below. Severe infestation causes leaf curling, stunted growth, blackened inflorescences, flower drop, and drying of immature capsules. Thrips can be spotted by tapping leaves or inflorescences over white paper.

Thrips damage on spike

Management:

- Spray Acetamiprid (0.2 g/L), Clothianidin (0.1 g/L), Fipronil (2 ml/L), or Thiamethoxam (0.5 g/L) at 15-day intervals.
- Alternate chemicals for effective management.

Wilt damage

Wilt Disease (*Fusarium oxysporum f.sp. ricini*)

Wilt affects seedlings and mature plants, causing yellowing, brittle leaves, and vascular discoloration.

Management:

- Practice crop rotation with non-host plants.
- Treat seeds with Thiram (3 g/kg) or Carbendazim (2 g/kg).
- Use biocontrol agents like *Trichoderma viride* (10 g/kg seed).
- Apply *T. viride* (2 kg mixed with 100 kg farmyard manure) to the soil.
- Drench soil with Copper Oxychloride (3 g/L).

Conclusion

Castor is an important oilseed crop, primarily grown in India, but faces significant threats from pests and diseases, including lepidopteran pests and fungal wilt. Integrated pest management strategies, such as using natural enemies, pheromone traps, neem oil, and selective chemicals, along with crop rotation and seed treatment, are crucial for minimizing yield losses and ensuring sustainable production.

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Integrating AI and ML to Enhance Productivity and Sustainability in Precision Agriculture

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Artificial Intelligence (AI) and Machine Learning (ML) are transforming precision agriculture by enabling data-driven decision-making, optimizing resource utilization, and enhancing sustainability. These technologies integrate with tools such as the Internet of Things (IoT), drones, and remote sensing to monitor crops, predict yields, and manage resources efficiently. AI-driven models facilitate real-time crop and soil monitoring, precise nutrient and irrigation management, and early detection of pests and diseases, leading to increased productivity and reduced environmental impact. The adoption of smart irrigation systems and predictive analytics has resulted in improved water use efficiency and climate resilience. Economically, AI contributes to higher yields and lower labor costs while supporting sustainable farming practices. Despite challenges such as high implementation costs, data privacy issues, and skill gaps, the integration of AI and ML in agriculture presents immense potential for achieving global food security and environmental sustainability.

Keywords: Artificial Intelligence, Machine Learning, Precision Agriculture, Sustainability, Resource Optimization, Crop Monitoring, Smart Irrigation

Introduction:

Artificial Intelligence (AI) and Machine Learning (ML) are revolutionizing precision agriculture by enhancing efficiency, sustainability, and productivity in farming practices. These technologies enable farmers to optimize resource use, improve crop yields, and reduce environmental impacts through data-driven insights and automation. AI and ML applications in precision agriculture encompass various aspects, including crop monitoring, soil analysis, water management, and pest control, thereby addressing the challenges of food security and environmental sustainability. The integration of AI with other technologies such as IoT, robotics, and remote sensing further amplifies its potential in transforming agricultural systems. Below are the key roles AI and ML play in precision agriculture:

Crop Monitoring and Yield Prediction

AI and ML facilitate real-time monitoring of crop health using remote sensing technologies like drones and satellites, which help in predicting yields and detecting early signs of stress or disease (Balasubramani et al., 2025) (Patibandla et al., 2024). This proactive monitoring allows for timely interventions, reducing losses and ensuring optimal resource allocation throughout the growing season.

Machine learning models analyze vast amounts of data to provide actionable insights for better crop management, enabling farmers to make informed decisions and improve productivity (Polwaththa et al., 2024) (Tanna et al., 2024). Furthermore, the use of AI-driven analytics can lead to a significant reduction in resource wastage, promoting more sustainable agricultural practices.

Soil Analysis and Nutrient Management

AI-driven models, such as neural networks and support vector machines, enhance soil analysis by providing rapid and accurate assessments of soil properties, including pH, nutrient availability, and texture (Rahman & Das, 2025). These insights enable farmers to tailor fertilization practices effectively, ensuring optimal nutrient utilization and minimizing environmental impact. These technologies optimize nutrient management by recommending precise applications of fertilizers and amendments based on real-time soil and crop needs, thus reducing waste and environmental impact (Balasubramani et al., 2025). Additionally, AI enhances pest control strategies by predicting pest outbreaks and recommending targeted interventions, ultimately contributing to healthier crops and reduced pesticide use.

Water Management and Irrigation

AI and ML improve water management through smart irrigation systems that optimize water use by 20-40%, contributing to resource efficiency and sustainability (Mishra, 2025). Moreover, these systems utilize real-time data to adjust irrigation schedules, ensuring crops receive the right amount of water at the right time, which is crucial for maintaining crop health and maximizing yields.

Predictive analytics enable farmers to anticipate climatic impacts and adjust irrigation practices accordingly, ensuring optimal water usage and reducing the risk of drought (Anicet et al., 2025) (Debnath et al., 2024). This integration of AI technologies not only enhances crop resilience but also promotes sustainable farming practices that are essential in the face of climate change and growing food demands (Patil, 2025). This holistic approach to precision agriculture fosters an adaptive framework that empowers farmers to respond effectively to environmental challenges and market fluctuations.

Pest and Disease Control

AI technologies, including computer vision and machine learning, aid in early detection of pests and diseases, allowing for timely interventions and minimizing crop losses (Falola et al., 2025) (Tanna et al., 2024). By leveraging advanced algorithms and data analysis, AI enhances the accuracy of pest and disease identification, ultimately improving crop health and yield while reducing reliance on chemical treatments.

Automated systems and robotics streamline pest control operations, enhancing labor productivity and operational efficiency (Polwaththa et al., 2024). This proactive approach not only safeguards crops but also aligns with sustainable agricultural practices that seek to minimize chemical usage and environmental impact.

Economic and Environmental Impact

AI adoption in precision agriculture leads to significant economic benefits, with a reported 30% increase in crop yields and a reduction in labor costs by up to 25% (Mishra, 2025). Furthermore, the integration of AI technologies can also contribute to enhanced environmental sustainability by optimizing resource utilization and minimizing waste, ultimately supporting global food security efforts. The transformative potential of AI in agriculture underscores the necessity for continued investment in technology and training to maximize these benefits for farmers worldwide.

The integration of AI with precision agriculture practices contributes to climate change mitigation by reducing carbon footprints and promoting sustainable farming methods (Kotagiri, 2025). This integration not only enhances agricultural productivity but also supports the urgent need for sustainable practices to combat climate change and ensure food security for future generations.

While AI and ML offer substantial benefits in precision agriculture, challenges such as high implementation costs, data privacy concerns, and the skills gap among farmers need to be addressed. Additionally, ethical issues like data ownership and the potential loss of jobs due to automation are critical considerations (Polwaththa et al., 2024) (Falola et al., 2025). Despite these challenges, the potential of AI to transform agriculture is immense, promising more sustainable and productive farming practices that can meet the growing global food demand.

Conclusion:

The integration of Artificial Intelligence and Machine Learning in precision agriculture significantly enhances efficiency, sustainability, and productivity. These technologies enable smart monitoring, resource optimization, and climate-resilient farming, leading to higher yields and reduced environmental impact. Despite challenges such as cost and skill limitations, AI and ML hold immense potential to revolutionize modern agriculture and ensure global food security.

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Development of Milking Systems and its Impact on Milk Quality

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Abstract

This review aims to summarise the development of milking systems, which influenced the quality of the milk and milk produced substantially, in past few decades. The milking environment is considered as one of the important factors for clean milk production. The milking systems were developed so as to keep the animal calm and comfortable while milking, which is attributed to have an advantageous effect on the quantity of the milk produced. Mechanisation of milking units has decreased the human intervention tremendously, yielding low labour requirement and reduced contamination due to human attributes. Many modernized techniques have been developed to facilitate proper and consistent milking practices. On the other hand, it has also improved the efficiency, safety and comfort of the labours involved in dairying. Quality milk production can only be achieved by adopting modern milking systems and good hygienic practices in and around the farm.

Keywords: Automation, Hygiene, Milking, Milk, Quality

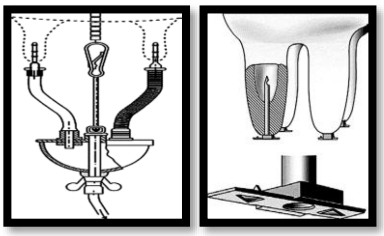
Introduction

According to the report of Department of Animal Husbandry and Dairying (2017), from a modest 17 million tonnes (MT) in the 1950s, milk production in India shot up to 163.7 MT in 2016-17. The production elevated by 20 per cent in 2016-17 compared to 2013-14. The per-capita milk availability increased from 307 grams per day in 2013-14 to 352 grams per day in 2016-17, recording a growth of 15.6 per cent. Also, the dairy farmers' income grew at the rate of 23.77 per cent during 2014-17 compared to 2011-14. Milk production of the animal directly reflects the implementation of welfare activities in a dairy farm (Sutherland et al., 2012). The adoption of milking machine has streamlined the care of animals and increased the quality of milk, but on the other hand, it may bring about many disorders of the udder (Twardon et al., 2001). With the help of milking machine, milk productivity can be increased and milking can be performed under more hygienic conditions. When the equipment is regularly maintained, it has a positive impact on udder and teat health, Somatic Cell Count (SCC) and ultimately on milk quality (Dang and Anand, 2007). On the other hand, if not used properly, a milking machine can significantly influence new infection rate. The dairy farmers are shifting towards advancements not only to reduce the farm labour requirement but also to improve the microbial quality of milk (Munyoro, 2014).

History of Milking Machines

Since the domestication of dairy animals, milking was done only by hand which prevailed for many centuries. First effort to circumvent the sphincter muscles of the teat was carried out in Egypt during 400 BC using quill feathers (Roginski et al., 2003). Real earnest work along the route of milking machines began in 1878. Milk extraction was based on three principles upon which the milking machines were fashioned, namely, Catheter Principle, Pressure Principle and Vacuum Principle.

Catheter Principle

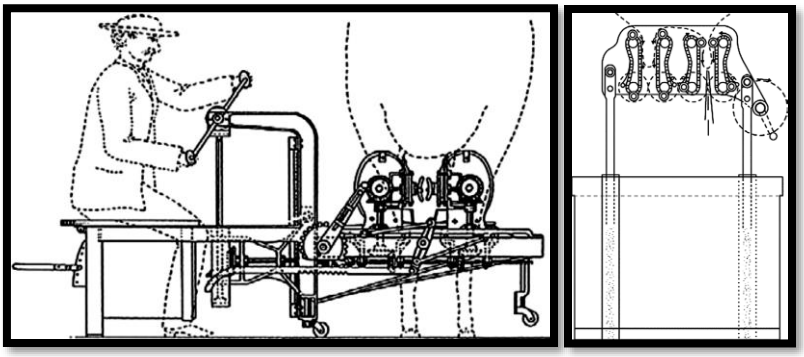


The machines were developed based on the principle of using a catheter, inserted into the teat duct, which allowed the milk to drain from the udder. Although this system is practical, in some instances, as in udder diseases, it becomes hazardous and impractical for average conditions (Roginski et al., 2003) as it is essential to sterilize that part of the device which is to be inserted into the teat canal.

Pressure principle

The machines were developed based on the principle of duplication of the technique of hand milking. The pressure was applied on the teat, at the attachment of the udder, closing the duct of the teat and a continuous downward pressure was applied to force the milk out of the teat cistern. Mechanically, hydraulically or pneumatically driven plates, bars, belts and rollers were used to simulate the action of hand milking (Roginski et al., 2003).

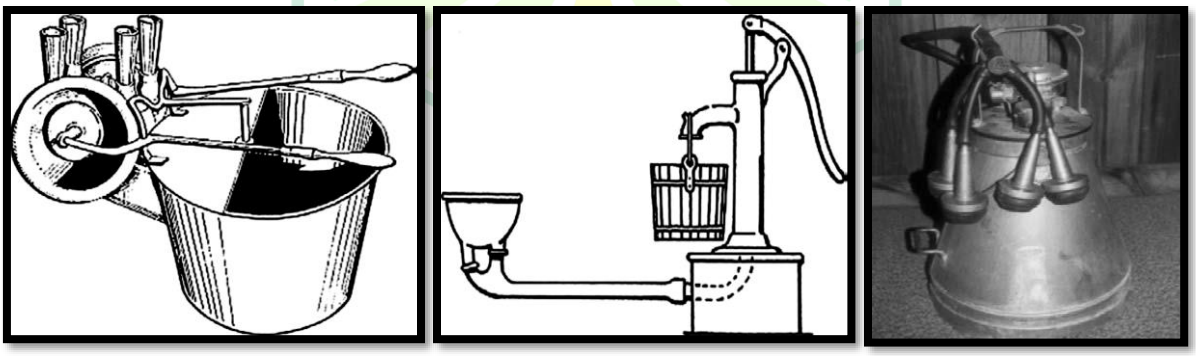
Some reasons for the failure of this design were, slower rate of milking compared to hand milking, lower milk yield, Teat injuries and high degree of operator skill required to operate these machines.



Vacuum principle

This principle employs the use of vacuum (suction) to imitate the sucking action of the calf. This principle worked on the basis of suction or negative pressure on the teat, the teats were placed in cups, from which the air was removed, producing a vacuum. Hence, the negative pressure of the air on the udder forced the milk into the teat and emptied into the vacuum chamber. The principle could be similar to that of the calf sucking the teat (Van, 1998). The initial idea of using a vacuum to extract milk from a cow is attributed to Hodges & Brocken den, in 1851. The actual principle of duplicating the action of the calf on the teat was not invented until suction pressure was produced at intervals. These intervals are called as pulsations. The intervals produced by the calf during feeding are due to an obvious reason that the calf is obliged to take its breath and continue to swallow. In the year 1895-96, first "Pulsator" was invented by Dr. Alexander Shields of Glasgow, Scotland (Thistle Mechanical Milking Machine Company).

The single-chambered teat cups pulsated between -15 to -50kpa, in a "swinging vacuum" milking machine(Van, 1998). In 1892, Struthers and Weir from Scotland introduced a double chambered teat-cup. This device was claimed to produce an intermittent pressure on the teat using a rubber diaphragm to neutralize the influence of vacuum on the teat. In 1918, Carl Patrik Gustaf de Laval invented the bucket milking machine – first commercially produced and marketed machine (Roginski et al., 2003).



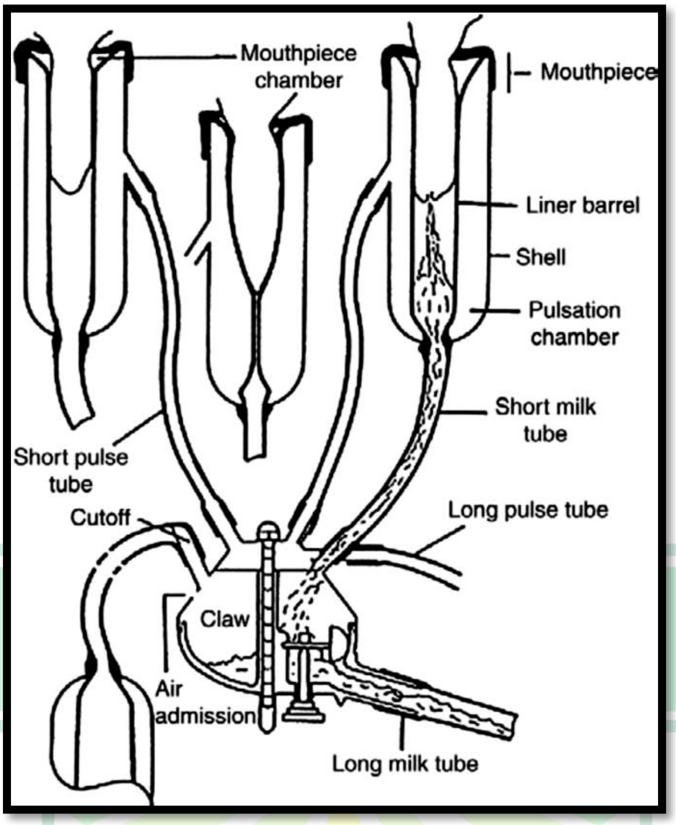
Milking machines

For machine milking to be economical, a minimum of 10 high yielder cows or buffaloes should be available at the farm. The principle behind the machine is generation of negative pressure or suction with the help of a vacuum pump.

Parts of a standard milking machine

Milking unit

A milking unit is the actual functional part in a milking machine. A typical milking unit consists of, 4 teats cups, short milk tube, short pulse tube, claw, long milk tube (hose) and a long pulse tube (hose). Teat cup is a double-chambered cup containing rigid outer shell made of stainless steel or plastic that holds a soft inner liner. The teat is inserted through the mouthpiece into the teat cup liner, where continuous partial vacuum is maintained. This whole set is combined to be called the "teat cup assembly" and the space between the liner and shell is called the "pulsation chamber". Normal atmospheric pressure and vacuum is alternated in this chamber by means of a "pulsator" through short pulse tubes branched out of a long pulse tube. Claw forms a junction for the milk collected from all the four teats, which is drained through short milk tubes, it also has a cut off to relieve the teats from the continuous partial vacuum after completion of milking. The milk is conducted through the long milk hose into the pail or container.



Pulsator

It is an air valve which alternately introduces vacuum and air at atmospheric pressure into the pulsation chamber. When vacuum is applied between the liner and shell, the rubber liner inflates allowing the milk to flow out of the teat, and when the chamber is filled with atmospheric pressure, the inflated rubber liner collapses, as a result, the teat is compressed and massaged (Howard, 1943).

Vacuum pump

A vacuum pump is a wane pump used to remove air from the milking system. It creates the necessary negative pressure.

Vacuum regulator

The vacuum level is controlled by vacuum regulation system. A typical vacuum regulator maintains a balanced vacuum level in the system by allowing air into the system (through detached milking units, air leaks, or other means) with the quantity of air being expelled by the vacuum pump. If more air is entering the system than being expelled, the vacuum level is dropped and the regulator closes. If more air is being expelled than entering, the vacuum level is increased, and the regulator opens to admit air.

Vacuum gauge

Every milking system is fitted with an accurate vacuum gauge. It is helpful in knowing the amount of vacuum maintained at any point of the time. The gauge must be visible to the operators during milking.

Factors influencing the efficiency of milking machine

Various factors must be considered for proper milking of animals without inflicting any pain or discomfort to the animal during milking process.

Vacuum level

The amount of vacuum in a milking system during milking can be expressed in terms of millimetres of Hg or inches of Mercury/kilo pascal (mmHg or inHg/kpa) differential quantified from atmospheric pressure and directed by the vacuum gauge. It must ideally be (-) 352mm Hg in Cattle and (-) 400mm Hg in Buffaloes (Rasmussen et al., 2003).

Pulsation rate

It is the number of cycles of alternating vacuum and atmospheric air which take place per minute. It may ideally vary between 40 to 60 cycles per minute in most of the machines (Akam et al., 1989).

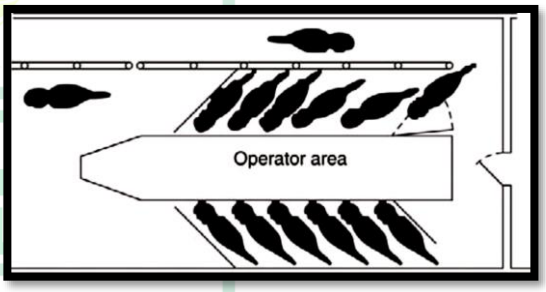
Milking or Pulsation ratio

The duration of time spent under vacuum and atmospheric air and is usually maintained between 1:1 and 2:1 (Akam et al., 1989).

Milking Parlors

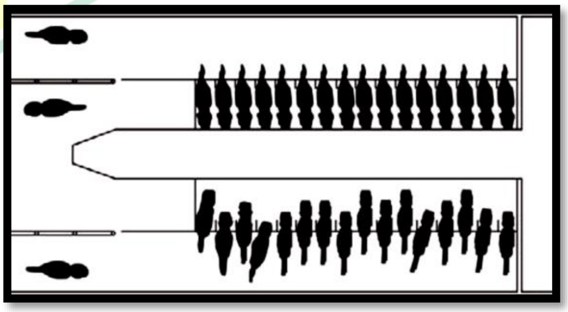
A milking Parlor is a building where the milking operation alone is carried out. Cows are brought to the milking Parlor to be milked and are then returned to a resting area. Milking parlours are classified based on whether the cows are raised above the person upon a platform, while milking (flat parlour or elevated parlour) the type of stall used, and entry and exit methods of the animals. The important types of milking parlours are discussed further.

Herringbone



In herringbone (or fishbone) parlours, cows stand on raised platforms on either side at an angle of 45^{o} to the operator's area. This alignment allows the operator to access the side of the cow for its preparation and unit attachment. In bigger parlours the two rows of stalls can be arranged in a wedge or "V" formation (Fig.6), providing a wider operator area on the opposite end away from the Parlor entrance. This enhances the visibility of units and cows from the opposite side of the operator area (Reinemann, 2013). Cows enter the parlour in groups according to the number of stalls on each side of the Parlor. The end portion of a herringbone stall is usually arranged in "S" configuration to position the caudal end of the cow in near proximity to the milking unit. The anterior end of herringbone stalls can be fitted with indexing stall and may use either standard or rapid exit.

Parallel



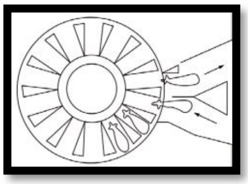
In parallel or side-by-side parlours, cows stand on raised platform at a 90^{o} angle to the operator area. This alignment allows the operator to access the udder for cow preparation and unit attachment in between the cows' hind legs (Fig.7). It is impractical to fit parallel stalls with arm type Automatic Cluster Removers (ACR) because of the restricted access to the udder (Roginski et al., 2003). Parallel stalls are generally fitted with indexing front ends and rapid exit along with dual return lanes. On comparison, the parallel configuration facilitates a shorter operator's area, reducing the distance walked by operators, than provided by herringbone parlours (Reinemann, 2013).

Side open or Tandem

In tandem stalls, cows stand in an end-to-end conformation during milking and milking units are attached from the side. This Parlor type is not affected by disparities in individual cow milking times when compared to herringbone or parallel parlours (Roginski et al., 2003), as cows move one at a time rather than in groups. This

Parlor also provides maximum view and access to cows for the operator during milking. This Parlor is ideally suited to situations in which individual care to the cows may be provided in individual cow milking times, as cows move one at a time rather than in groups.

Rotary or Carousel



In rotary or carousel parlours, cows stand on a rotating milking platform one after the other. An operator performs cow preparation and unit attachment functions. The stalls in rotary parlours may vary from 10 to 80 or more. Rotary parlours aid an orderly and constant milking routine in large parlours (Roginski et al., 2003).

Robotic Milking system

Automatic Milking Systems (AMS), also called Voluntary Milking Systems (VMS), have been commercially available since the early 1990s. Automated milking is also called robotic milking systems as these rely on the use of computers and special herd management software (Spahr and Maltz, 1997). Voluntary milking allows the cow to decide her own milking time and interval. It requires complete automation of the milking operation as the cow may choose to be milked at any time. When cow tries to enter the milking unit, a cow Radio Frequency Identification Device (RFID) sensor reads an identification tag attached to the cow and passes the cow's ID to the control system (Artmann, 1997). This is to avoid frequent access to highly palatable feed that is provided in the milking unit (Prescott et al., 1998). The automatic gate system directs the cow out of the milking unit if the cow is milked too recently (Hermans et al., 2003; Bach et al., 2009). If the cow is to be milked, automatic teat cleaning, teat cup application, milking, and antiseptic spraying on teat occurs. Concentrated feed is fed to the cow, as an incentive to attend the milking unit (Wierenga, 1991; Madsen et al., 2010). Management Information System (MIS) can be used to process data of milk ability, udder health and overall health of cow and correlate the performance of each cow, making it simpler to take farm management decisions. This ensures that each cow is attaining its full production potential and efficient utilisation of all the resources (Devir et al., 1997). Normal capacity of an AMS is 60-80 cows per milking unit/day (André et al., 2010). AMS usually achieves milking frequencies between 2 to 3 times per day (Klei et al., 1997). To achieve optimum efficiency through AMS various factors have to be considered such as milk yield, milking frequency, inter-milking period, time required for milking, cow traffic control and teat cup attachment (Gygax et al., 2007). During the milking, the animals are housed in the box. It is impossible to make the cow stand still and hence the position of the teat continuously. The relative teat positions should not vary more than 0.5-1cm in a given system and teat structure (Rossing & Hoeger, 1997). AMS is not compatible to all the cows in the herd due to the varied teat positions and udder structure. The farmers are guided by the manufacturer as to which animals will be suitable for AMS and therefore, the cows should be selected based on it. In general, on an average, an AMS is not suitable for 5-15 per cent of the animals in a prevailing herd, primarily because of udder shape and teat position (Rotz et al., 2003). The milk collected in AMS has lower Somatic Cell Count (SCC) and Electric conductivity (EC) when compared to the conventional milking systems (Berglund et al., 2002; Kamphuis et al., 2010). This is due to the number of milking frequencies (2 to 3) achieved in AMS (Campos et al., 1994; Dahl et al., 2004; Garcia and Fulkerson, 2005) and hence lower bacterial counts seen in the milk of AMS milked animals (Hillerton, 1991; Speicher et al., 1994) as the bacterial population is reduced or nullified upon frequent milking of animals. The decreased bacterial load can also be attributed to the rinsing of the teat cups between each cow (Berglund et al., 2002). The teat dip used after milking helps in the closure of teat sphincter and avoids the dryness of the teat skin apart from the sanitisation of teat opening.

Conclusion

Milking of cows has transformed from the simple method of hand milking to robotic milking systems. The technological development has not only resulted in increase in the quantity of milk, but also in the quality of milk. Automation of milking has paved way for the establishment of mega dairy farms where milking operations is practiced round the clock. Automation in cell counting has resulted in deviation of milk with high SCC, from the milk pool, improving the quality of milk. Automation in parlours has also improved the environmental hygiene around the animal during milking. Though in the last decade, we have seen Hi-tech technologies from milking machine to AMS, most of these technologies could not be adopted by majority of the farmers in developing countries like India due to high initial cost. Therefore, development of economical and efficient milking system has become the need of the hour.

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FROM BLOSSOM TO BARREN: HOW MANGO HOPPERS ENDANGER FRUIT DEVELOPMENT

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Abstract

Mango (*Mangifera indica* L.) is one of the most important tropical fruits cultivated worldwide, particularly in India. Among the major insect pests, mango hoppers (*Idioscopus* spp.) are considered highly destructive, causing significant yield losses during the flowering and fruit-setting stages. Both nymphs and adults feed by sucking plant sap, which leads to withering of inflorescences, flower and fruit drop, and promotes the growth of sooty mold through honeydew secretion. The biology of mango hoppers is characterized by rapid multiplication and several generations in a season, coinciding with the flowering period. This article reviews the taxonomy, life cycle, symptoms of damage, and factors favoring hopper infestation. Traditional management practices, such as pruning, use of neem-based extracts, and orchard sanitation, are widely employed, while modern strategies include the use of selective insecticides and biological control agents like predators and entomopathogenic fungi. Integrated Pest Management (IPM) approaches combining cultural, biological, and chemical methods provide the most sustainable and eco-friendly solution for managing hopper infestations and ensuring higher mango productivity.

Keywords

Mango hoppers, *Idioscopus*, pest management, life cycle, sooty mold, integrated pest management (IPM), biological control, sustainable agriculture

Introduction

Mango (*Mangifera indica* L.) is often referred to as the "King of Fruits" and holds immense economic and cultural significance in India and many tropical and subtropical regions of the world. India is the largest producer of mango, contributing nearly half of the global production, and the crop serves as a livelihood source for millions of farmers. However, mango production is severely constrained by several insect pests, of which mango hoppers are considered the most destructive.

Mango hoppers, belonging to the genus *Idioscopus* (family Cicadellidae, order Hemiptera), are notorious for causing heavy yield losses, particularly during the flowering and fruit-setting stages. They occur abundantly in almost all mango-growing regions of India and are capable of reducing crop yield by 60–90% under severe infestation. Both nymphs and adults suck sap from tender shoots and inflorescences, leading to withering, drying of flowers, fruit drop, and reduced fruit quality. Additionally, the honeydew secreted during feeding encourages the growth of sooty mould, which interferes with photosynthesis and further weakens the plant.

Due to their rapid multiplication, adaptability, and the vulnerability of mango during flowering, hoppers remain a persistent challenge for growers. Traditional management practices, such as orchard sanitation and neem-based extracts, are commonly used, while modern approaches rely on selective insecticides and biological control agents. Sustainable and eco-friendly management through Integrated Pest Management (IPM) is crucial to minimize crop losses and safeguard beneficial organisms like pollinators.

Biology and Life Cycle of Mango Hoppers

Mango hoppers, belonging to the genus *Idioscopus* (family Cicadellidae), are small, wedge-shaped insects that reproduce rapidly and are well adapted to mango ecosystems. Their biology and life cycle are closely synchronized with the phenology of mango, especially during flowering and fruit setting. The three important species infesting mango in India are *Idioscopus clypealis*, *I. niveosparsus*, and *Amirtodus atkinsoni*

Egg Stage

- Female hoppers lay their eggs singly or in clusters inside the tender tissues of flower buds, flower stalks, or tender shoots.
- The eggs are inserted within the plant tissue using the ovipositor, making them less visible to the naked eye.
- The incubation period varies from 4 to 7 days, depending on temperature and humidity.

Nymph Stage

- Nymphs emerge after hatching and resemble miniature adults but are wingless.
- They are pale yellow to green in color, highly active, and feed voraciously on plant sap.
- Nymphal development passes through five instar stages.
- The total nymphal period ranges between 7 to 10 days.

Adult Stage

- Adults are wedge-shaped, brownish to green insects with transparent wings.
- They are strong jumpers and highly mobile within the mango canopy.
- Both males and females feed on plant sap, but females are more damaging due to their feeding and oviposition activity.
- Adults live for 10 to 20 days, and each female lays about 20–25 eggs in her lifetime.

Seasonal Biology

- The life cycle from egg to adult completes in 2 to 3 weeks, allowing multiple overlapping generations in a single flowering season.
- Peak population is observed during February to April, coinciding with mango flowering, when favorable warm and humid conditions prevail.
- Population density declines after fruit set but may rise again in regions with extended flowering.

Summary of Life Cycle

Egg (4–7 days) → Nymph (7–10 days; 5 instars) → Adult (10–20 days)

- **Total duration**: 20–30 days, with 8–10 generations possible per year in favorable climates.

Nature of Damage and Symptoms

Mango hoppers are considered the most destructive insect pests of mango, particularly during the flowering and fruit-setting stages. Both nymphs and adults are highly active sap feeders, and their feeding activity directly and indirectly affects the crop yield and quality.

Mode of Damage

- Nymphs and adults insert their piercing-sucking mouthparts into the tender tissues of inflorescences, leaves, and young shoots.
- Continuous sap sucking causes depletion of plant vitality, resulting in wilting and drying of flowers.
- Female hoppers, during oviposition, further injure flower buds and stalks, aggravating the damage.
- While feeding, the insects excrete large amounts of honeydew, a sugary substance that serves as a medium for the growth of sooty mold fungi.

Idioscopus niveoparsus

I. clypealis

Amirtodus atkinsoni

Source :- https://agritech.tnau.ac.in/

Symptoms of Infestation

1. Inflorescence Drying – Tender flower stalks and buds wither and dry due to sap loss.
2. Flower and Fruit Drop – Pollination and fruit set are severely hampered, leading to heavy yield losses.
3. Sooty Mold Development – Black fungal growth on leaves, flowers, and fruits develops on honeydew deposits, which reduces photosynthetic activity.
4. Stunted Growth – Tender shoots show curling, yellowing, and reduced vigor.
5. Reduced Fruit Quality – Fruits covered with sooty mold appear unattractive and fetch lower market prices.

Sooty Mold

Inflorescence Drying

Source :- https://agritech.tnau.ac.in/

Extent of Damage

- Severe hopper infestation during peak flowering may cause 60–90% yield loss.
- Inflorescences may completely dry before fruit set, drastically reducing productivity.
- Secondary infections by molds and fungi further weaken the plant.

Management / Control Measures

Effective management of mango hoppers requires a holistic approach that combines traditional, biological, and modern chemical methods. Since the pest coincides with mango flowering – a critical stage for pollination and fruit set – pest control must be timely, selective, and eco-friendly to minimize harm to pollinators like honeybees.

1. Cultural and Traditional Practices

- Pruning and Canopy Management – Regular pruning improves sunlight penetration and air circulation, reducing favorable microclimates for hopper multiplication.
- Orchard Sanitation – Removal of dried twigs, old inflorescences, and weeds helps in reducing hopper breeding sites.
- Use of Traditional Repellents – Farmers often use ash, cow dung smoke, or locally prepared herbal decoctions to repel hoppers during flowering.
- Balanced Nutrition and Irrigation – Avoid excessive nitrogenous fertilizers and over-irrigation, as they promote tender flushes that favor hopper infestation.
- Neem Seed Kernel Extract (NSKE 5%) or neem oil sprays (2%) are highly effective, eco-friendly traditional practices.

2. Biological Control

- Predators –
  - Green lacewing (*Chrysoperla carnea*)
  - Ladybird beetles (*Coccinella septempunctata*)
  - Spiders naturally prey upon hopper nymphs and adults.
- Parasitoids – Egg parasitoids such as *Trichogramma* spp. and Dryinid wasps help regulate hopper populations.

- Entomopathogenic Fungi – *Beauveria bassiana* and *Metarhizium anisopliae* formulations have shown promising results under field conditions.

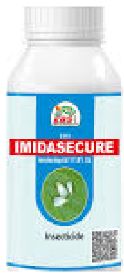
Green lacewing **Ladybird beetles**


Source :- https://agritech.tnau.ac.in/

3. Chemical Control

- Insecticides are most effective when applied at the initiation of flowering and repeated at 10–15 day intervals depending on hopper population.
- Recommended insecticides:
  - Imidacloprid 17.8 SL (0.3 ml/L)
  - Thiamethoxam 25 WG (0.25 g/L)
  - Lambda-cyhalothrin 5 EC (1 ml/L)
  - Dimethoate 30 EC (2 ml/L)
- Precautions:
  - Avoid spraying during full bloom to protect pollinators.
  - Rotate chemicals to delay resistance development.
  - Use selective, low-residual insecticides instead of broad-spectrum ones.

Imidacloprid **Dimethoate** **Thiamethoxam**



Source :- https://agritech.tnau.ac.in/

4. Integrated Pest Management (IPM)

A sustainable solution lies in combining cultural, biological, and chemical methods. The following IPM strategy is recommended:

1. Monitoring hopper population using yellow sticky traps.
2. Pruning and sanitation to reduce initial pest load.
3. Use of neem-based botanicals as first-line defense.
4. Release of natural enemies (e.g., *Chrysoperla carnea* larvae).
5. Judicious insecticide sprays only when hopper population exceeds the economic threshold level (5 hoppers per panicle).

Conclusion

Mango hoppers (*Idioscopus* spp.) are among the most destructive pests of mango, causing severe yield losses by directly feeding on sap and indirectly promoting the growth of sooty mold. Their rapid multiplication during the critical flowering stage makes them a major challenge for mango growers. Traditional cultural practices, combined with biological control agents and eco-friendly botanicals like neem, offer sustainable alternatives to chemical pesticides. However, in cases of severe infestation, need-based use of selective insecticides remains necessary, with due care to protect pollinators and prevent resistance.

The future of hopper management lies in Integrated Pest Management (IPM), which brings together monitoring, cultural practices, biological regulation, and judicious chemical use. Adoption of IPM not only ensures effective suppression of hopper populations but also minimizes environmental risks, safeguards pollinators, and enhances mango productivity. Sustainable pest management strategies will therefore play a vital role in protecting the "King of Fruits" and securing the livelihoods of millions of farmers dependent on mango cultivation.

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Procurement to Prosperity: A Success Story of Gram Vishwas Farmers Producer Organization

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Introduction

Farmers are the backbone of India's economy, yet they often struggle to get fair prices for their hard-earned produce. One of the biggest challenges they face is finding reliable market linkages that ensure steady and remunerative returns**.** In most cases, prices in the market are determined by demand and supply. Sometimes, these prices fall so low that farmers cannot even recover their cost of production. To protect farmers from such losses, the Government of India introduced the **Minimum Support Price (MSP**) system for 22 major crops and a Fair and Remunerative Price (FRP) for sugarcane. The MSP is fixed at 1.5 times the all-India average cost of production, ensuring at least 50% profit over costs. The Commission for Agricultural Costs and Prices (CACP) recommend the MSP, which is then approved by the Cabinet Committee on Economic Affairs (CCEA) and announced by the Government of India.

Building on this idea of helping farmers get fair prices, Gram Vishwas Farmer Producer Company Limited has taken important steps to support farmers through procurement and value chain activities in soybean and redgram. These efforts have not only helped farmers earn better income but have also made the Farmer Producer Organization (FPO) more strong, sustainable, and self-reliant.

Evolution of GVFPCL

The **Gram Vishwas Farmer Producer Company Limited (GVFPCL)** was established on **February 4, 2022**, and is one of the twelve Farmer Producer Organizations (FPOs) promoted by **ICAR - Indian Institute of Millets Research (IIMR), Hyderabad and SFAC, New Delhi** under the **Centrally Sponsored Scheme (CSS)** for the **Formation and Promotion of 10,000 FPOs**.

Fig 1. Mehkar Farmers' 1st Visit to ICAR-IIMR to Explore the Formation of FPO

GVFPCL comprises **750 farmer shareholders** from **six villages in Bhalki taluka**, located in the **Bidar district** of Karnataka. The region predominantly consists of **black cotton soils**, which are highly fertile and suitable for cultivating a variety of crops such as **soybean, redgram, safflower, black gram, and bengal gram**.The journey of **Gram Vishwas Farmer Producer Company Limited (GVFPCL)** began in the village of **Mehkar**, where a group of like-minded farmers shared a common dream — to bring positive change to their village and uplift the farming community. Inspired by the idea of collective strength, these farmers united with a shared purpose. Realizing the potential of working together, they reached out to **ICAR - Indian Institute of Millets Research (IIMR), Hyderabad** for support and guidance.

ICAR-IIMR not only encouraged the farmers' initiative but also provided technical support and mentorship to help shape their vision. To ensure a strong foundation for the FPO, ICAR-IIMR organized training programs for the elected directors of GVFPCL at its Hyderabad campus. These sessions covered key aspects of effectively managing and operating a Farmer Producer Organization. As a result of this strong foundation and capacity building, the GVFPCL team was able to successfully mobilize 610 farmers in the initial phase — a task that is never easy. The early training and guidance played a crucial role in achieving this milestone

FPO Profile

Table 1: FPO Profile

S.No	Particulars	
1	Date of registration	04/02/2022
2	Number of shareholders (farmers)	750
3	Share Capital Mobilized (INR- Lakh)	15,00,000/-
4	BoD members	5
5	Promoting organisation	ICAR-Indian Institute of Millet Research, Hyderabad
6	Channels of marketing	MSP procurement centre, Local market, Distributors, Processors e-NAM, APEDA, ONDC, GEM, Mystore
7	No. of Villages covered	06
8	Source of finance	Small Farmers' Agribusiness Consortium (SFAC) under the Department of Agriculture, Cooperation & Farmers' Welfare within the Ministry of Agriculture and Farmers Welfare, Government of India
9	Turnover	Rs. 1,53,00,000/-
10	Licenses Obtained	Input, Mandi, FSSAI, Seed, APEDA

Fig 2. Banner put up in villages to reach farmers and spread awareness

Fig 3. Inauguration of Gram Vishwas FPCL at Mehkar village

With renewed confidence and clarity, the farmers took the leap and formally registered **the GVFPCL**, marking the beginning of a new chapter in community-led agricultural development.

From the outset, the FPO has shown remarkable initiative. They swiftly acquired all the required licenses, including

- **APMC/Trade License**
- **FSSAI Registration**
- **Input License**
- **APEDA Certification**
- **NSC License**
- **ADM for procurement**

Fig 4. FPO representatives meeting JDA Bidar for input license approval

With these licenses in place, GVFPCL commenced operations, including the **sale of agricultural inputs** such as seeds, fertilizers, and pesticides, and **the procurement and marketing** of farm produce from its member farmers.

Seed Distribution: A Step Towards Farmer Empowerment

In its first year, GVFPCL made a significant impact by distributing **soybean seeds directly to the doorsteps of all 750 member farmers**. This doorstep delivery model saved farmers both time and transportation costs, as they no longer had to travel to the **Raita Samparka Kendra** to purchase seeds. The quality of the seeds was also appreciated by the farmers, which built further trust in the FPO.

Table 2: GVFPCL's Seed Distribution Summary

Sl.No	**Seed**	**Quantity Distributed (Kg)**			**No of farmers Benefitted**		
		2022-23	**2023-24**	**2024-25**	**2022-23**	**2023-24**	**2024-25**
1	**Soyabean**	30000	15300	18600	610	410	380
2	**Redgram**	2200	3800	2900	200	240	258

Fig 5. Seed Distribution at Shareholding Farmer's Door Step

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The Marketing Challenge: A Turning Point

While the seed distribution initiative was a success, the **post-harvest marketing** of soybean emerged as a major challenge. After harvesting, farmers were forced to travel over **100 km to Latur**, Maharashtra, to sell their produce. This journey significantly increased their marketing expenses, eroding the profits they could have earned.

This situation led to a valid and pressing question from the farmers:

After the FPO Delivered Soybean Seeds to Farmers' Doorsteps, a New Question Emerged: What About Post-Harvest Marketing?

The FPO soon realized that while **cultivation is the foundation**, **marketing is the backbone** of a successful farming ecosystem. The lack of nearby procurement infrastructure made farmers feel unsupported and discouraged, despite their collective efforts.

Responding to the Farmers' Need: Establishment of a Collection Centre

Acknowledging the genuine concerns raised by its members, GVFPCL took swift action. With the continued guidance of **ICAR-IIMR**, the FPO applied for a MSP **Procurement Centre**, which would allow centralized procurement, grading, and storage of farm produce closer to the villages.

Fig 6. Collaborative discussion between FPO team and farmers to solve marketing problems

Fig 7. Three-day training program on marketing at Mehkar village

Approval for the procurement center was successfully obtained in September 2024, and procurement activities commenced in November 2024. One of the major milestones achieved during this period was the highest number of farmers registered under an FPO in Karnataka state for the 2024–25 season.

In order to help the farmers to get remunerative prices for their produce with a view to encourage higher investment in agriculture and also to increase production and productivity of agricultural commodities, Government of India declares Minimum Support Price (MSP) for 22 notified agricultural commodities during both Kharif & Rabi crop seasons. National Agricultural Cooperative Marketing Federation of India Ltd. (NAFED) operates as one of the Central Nodal Agency for procuring 15 designated Agricultural Commodities, including Oilseeds, Pulses, and Copra, under the Minimum Support Price. Soybean and Redgram are major crop for 2 out of the 21 Farmer Producer Organizations (FPOs) promoted by ICAR-IIMR in Karnataka state.

The company decided to procure Soybean directly from the growers' house. For the purpose, the FPO established a procurement/collection center at Mehkar. The FPO started with imparting training to farmers about quality standards and different strategies to market their produce. One of the directors of the company visits the procurement center during the procurement time to ensure the procurement process. Apart from the director, the CEO and the marketing manager of the FPO also manage the operations of the procurement of soyabean and redgram. FPO bought jute bags to carry the produce. Traditionally, the growers bring their produce in their own jute bags which cost around Rs20 (50 kgs) to the growers**.** The procurement information was widely circulated through the press and social media to reach the farmers of the region

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The GVFPCL soybean MSP procurement center was inaugurated on 6th November 2024 by Shrimati. Sheetal Kamble, Gram Panchayat President in the presence of farmers and board members of FPC in Mehkar. The establishment of the Soya MSP procurement center has significantly benefited farmers. Farmers in and around FPCL were happy with the establishment of the Soya procurement center and made prompt use of the opportunity. The FPO did not restrict its procurement activities to Soybean alone from November to December 2024. When Redgram was harvested in January 2025 and market prices were found to be very low, the FPO immediately initiated Redgram procurement right after completing Soybean procurement, thereby supporting farmers during a crucial time.

Fig 8. Farmer Registration for Procurement

Procurement Highlights:

Gram Vishwas FPO achieved a major operational milestone by successfully procuring Redgram (Tur) and Soybean during the 2024–25 procurement season through its newly established procurement center.

- Approval for the procurement center was obtained in September 2024, and operations commenced in November 2024.
- The FPO procured redgram at an MSP of ₹7,550 per quintal, and with an additional incentive of ₹450 from the Karnataka state government, farmers received a total of ₹8,000 per quintal, while soybean was procured at an MSP of ₹4,892 per quintal
- **Within just six months**, GVFPCL procured a total of:
  - **4,048.5 quintals of Redgram from 608 farmers**
  - **2,922 quintals of Soybean from 214 farmers**
- The total procurement value was:
  - **₹3.24 crore for Redgram**
  - **₹1.44 crore for Soybean**

Tabel 3: Market vs. FPO Procurement Price Comparison

Crop	Local Market Price (₹/quintal)	GVFPCL Procurement Price (₹/quintal)	Additional Profit to Farmers (₹/quintal)	Quantity Procured (Q)	Total Additional Farmer Benefit (Approx.)	No of farmers benfitted
Redgram	7,000	8,000	1,000	4,048.5	₹40.48 lakh	608
Soybean	4,000	4,892	892	2,922	₹26.06 lakh	214

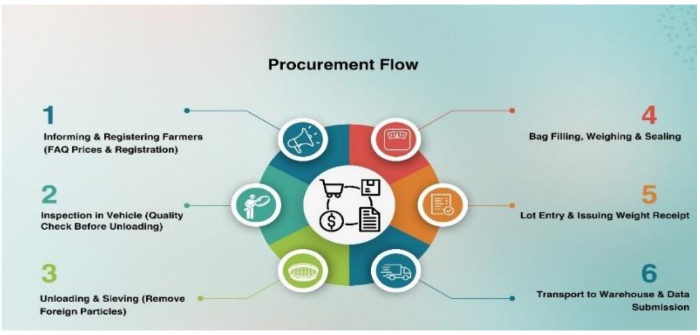

Fig 9. Procurement Flow

In addition to the price benefit, farmers also saved an estimated ₹800–₹1,000 per quintal on transportation, commission, labor, and other marketing expenses, since GVFPCL handled the entire procurement process locally. GVFPCL earned commission on the total value of the produce procured

Tabel 4: FPO Revenue from Commission

Crop	Value of Produce Procured	Commission Earned by FPO
Redgram	₹3.24 crore	₹3.24 lakh
Soybean	₹1.44 crore	₹1.44 lakh
Total	**₹4.68 crore**	**₹4.66 lakh**

Is This Not Sustainability? GVFPCL Earns ₹4.6 Lakh in Just Six Months

In just six months, through the procurement of only two crops, GVFPCL earned a commission of ₹4.66 lakh, demonstrating that output marketing is a key driver of FPO sustainability when there is timely market linkage and fair pricing.

Moreover, farmers not only benefited from higher procurement prices but also enjoyed significant savings on logistical costs. This model proves that with the right infrastructure and support, FPOs can play a critical role in increasing farmers' incomes and ensuring their participation in formal market systems.

GVFPCL's success with Redgram and Soybean procurement serves as a replicable model for other FPOs across the country**.**

Fig 10. Soybean and redgram Being Procured from Framer

Fig. 11. Procured produce, safely stored in FPO Godown

Fig 12. Procured redgram and soybean on the Way to NAFED Godown

Fig 13. Unloading Farmers Produce at NAFED Godown

Way Forward:

GVFPCL has successfully established both a Procurement Center and an Additional Procurement Center (ADM), through which it has been procuring Redgram and Soybean directly from farmers and supplying them to these centers. However, these centers have a procurement limit per farmer, which has led to a new challenge,

How to handle the surplus quantity of produce beyond procurement ceiling?

To address this, the FPO approached ICAR-IIMR for guidance. With their technical support, the FPO is now planning to set up a processing and value addition unit for surplus Soybean. By processing Soybean into value-added products like soya milk and soya tofu, the surplus can be efficiently utilized and marketed.

This initiative has strong potential. **Soya milk and tofu serve as excellent perfect substitutes** for milk and paneer. Since dairy farming is limited in the region, people often depend on milk and milk products from neighbouring districts.

By processing locally grown Soybean into soya milk and tofu, the FPO not only creates market linkage for surplus produce but also promotes the **'Local for Vocal'** vision by encouraging local production, local processing, and local consumption.

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Hydrogels and Their Applications in Agriculture

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1. Introduction

Water is a fundamental requirement for agriculture, and its efficient management is vital for enhancing crop productivity. With the looming threat of water scarcity due to climate change, urbanization, and increasing food demand, sustainable water management practices are urgently needed. One such promising innovation is the use of **hydrogels**, also known as **superabsorbent polymers (SAPs)**. These are capable of absorbing and retaining large amounts of water, making them ideal for improving water-use efficiency in agriculture. Hydrogels play a vital role in **soil moisture conservation, nutrient retention**, and **drought mitigation**, especially in water-limited and rainfed conditions. Their application aligns with modern agronomic goals such as **climate-resilient farming**, **resource-use efficiency**, and **sustainable soil health** management.

2. What Are Hydrogels?

Hydrogels are **three-dimensional, hydrophilic polymer networks** that can absorb, swell, and retain water within their structure without dissolving. The hydrophilic groups (such as –COOH, –OH, –CONH2) attract water molecules, allowing these materials to hold between **100 to 1500 times their own weight in water**, depending on polymer type and environmental conditions.

2.1 Types of Hydrogels

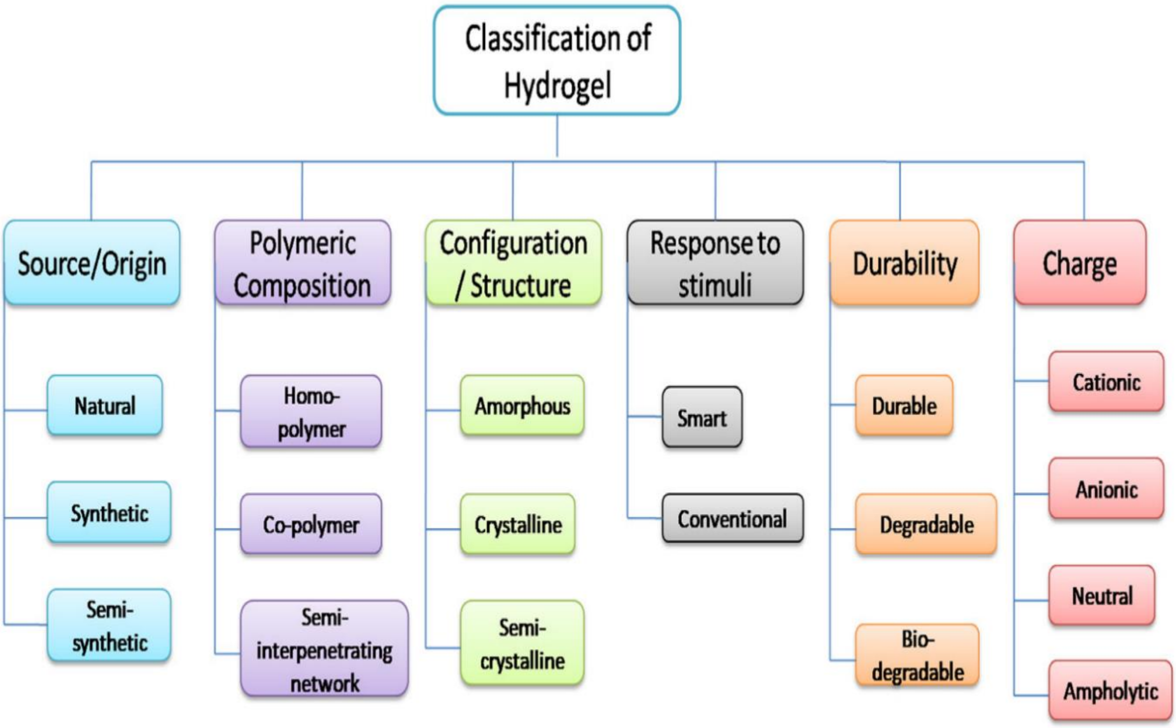
- **Synthetic Hydrogels**:
  - Made from petroleum-derived polymers like **polyacrylamide**, **polyacrylate**, and **polyvinyl alcohol**.
  - They are durable, have high swelling capacity, and are less biodegradable.
  - Used in field crops, horticulture, and turf management.
- **Natural Hydrogels:**
  - Derived from biopolymers like cellulose, chitosan, starch, guar gum, and alginate.
  - Eco-friendly, biodegradable, but often have lower water retention capacity and shorter life spans.
  - Preferred in organic and sustainable agriculture.
- **Hybrid or Composite Hydrogels:**
  - Combine natural and synthetic polymers to optimize strength, biodegradability, and water retention.
  - Examples include chitosan-grafted acrylamide and starch-based composites.

3. Mechanism of Action in Agricultural Soils

When applied to soil, hydrogels absorb and store water from irrigation or rainfall. The mechanism involves:

- **Water Absorption**: Hydrogels swell and retain water in their structure.
- **Slow Release**: Water is gradually released into the soil matrix as it dries, providing consistent moisture availability to plant roots.
- **Soil Pore Interaction**: Hydrogels improve soil porosity and reduce compaction by maintaining micro-aggregates.
- **Root Zone Regulation**: Hydrogels keep the **rhizosphere (root zone)** moist, enhancing root growth and microbial activity.

This process not only enhances water-use efficiency but also promotes **root proliferation, nutrient solubilization**, and **stress tolerance** in plants.



4. Applications of Hydrogels in Agriculture

4.1 Soil Moisture Conservation

Hydrogels act as **soil conditioners**, improving the water-holding capacity, especially in **sandy or degraded soils**. They minimize **surface runoff** and **deep percolation losses**, allowing longer retention of moisture in the root zone.

Example: In arid regions of Rajasthan and Gujarat, farmers use hydrogel-treated soils in vegetable cultivation to retain moisture between irrigation intervals.

4.2 Drought Mitigation and Stress Management

By keeping moisture available during dry spells, hydrogels mitigate **physiological stress** caused by water deficits. This improves photosynthesis, reduces **leaf wilting**, and supports **better grain filling and yield formation**.

Experimental Result: Studies in maize and sorghum show a **20–35% increase in biomass** and **up to 25% yield gain** under deficit irrigation with hydrogel application.

4.3 Seed Germination and Plant Establishment

Hydrogels ensure a **uniform moisture environment** around the seed, supporting better germination and seedling vigor. This is particularly beneficial in **direct-seeded rice (DSR)**, pulses, and vegetables under rainfed conditions.

- **Seed priming** with hydrogel or hydrogel-seed coating enhances uniform emergence and early root development.

4.4 Fertilizer Efficiency and Nutrient Management

Hydrogels reduce **leaching and volatilization losses** of fertilizers, especially nitrogen. When combined with urea or other fertilizers, hydrogels act as a **slow-release carrier**, improving nutrient uptake.

- **Hydrogel-fertilizer** complexes increase nitrogen-use efficiency (NUE) and phosphorus availability in alkaline soils.

4.5 Nursery Management and Transplanting

In nurseries and during transplanting operations, hydrogels retain moisture near the **root ball**, reducing transplant shock and improving plant survival.

- Used in raising seedlings of rice, tomato, chili, brinjal, and flowers.
- A hydrogel root dip is recommended before transplanting to enhance establishment under dry conditions.

4.6 Container and Protected Cultivation

Hydrogels are ideal for **greenhouses, polyhouses**, and **container gardening**, where root volume and water supply are limited.

- Reduced irrigation frequency by 30–50%.
- Maintains uniform soil moisture in grow bags and vertical farming setups.

4.7 Reclamation of Problem Soils

Hydrogels improve water retention and structure in **sandy, saline, and degraded soils**, facilitating the cultivation of otherwise low-productivity lands.

- In coastal saline soils, hydrogels mitigate salt stress by diluting salt concentrations and buffering osmotic stress.

5. Commercial Hydrogel Products and Application Rates

Hydrogels are commercially available as **granules, powders, or crystals**, and are applied directly into the soil or mixed with compost.

Product Name	Composition	Recommended Dose	Crop Use
Stockosorb	Cross-linked polyacrylate	1–3 kg/ha or 0.5 g/plant	Field crops, horticulture
Zeba	Corn-starch based	5–10 kg/ha	Vegetables, ornamentals
AgroHydrogel	Polyacrylamide	3–6 kg/ha	Pulses, cotton, maize
Aquasorb	Acrylic copolymer	2–5 kg/ha	Flowers, turfgrass
Terrafertil	Natural polymers	4–8 kg/ha	Fruits, plantations

Application Methods:

- **Soil mixing before sowing**
- **Band placement along rows**
- **Root dipping during transplanting**
- **Mixing with compost or biofertilizers**

6. Limitations and Challenges

While hydrogels offer many benefits, several constraints exist:

- **Cost**: High cost of synthetic hydrogels can limit large-scale adoption.
- **Environmental Impact**: Non-biodegradable hydrogels may accumulate in soil.
- **Salt Sensitivity**: Performance reduces in saline water due to ionic interference.
- **Field Handling**: Requires uniform mixing and proper application to avoid clumping.

To overcome these, research is being directed toward **low-cost natural hydrogels**, **bio-based composites**, and **site-specific formulations**.

7. Advantages and disadvantages of biopolymer based hydrogels in agriculture

Advantages	Description	Disadvantages	Description
Water Retention	Increase water holding capacity.	Low Mechanical Strength	Natural materials typically have lower inherent mechanical strength.
Controlled Release of Nutrients	More efficient nutrient uptake, reduces nutrient leaching, and minimizes fertilizer wastage.	Expensive to Produce	The initial investment might be a barrier to adoption for some farmers, particularly those with limited funds.
Improved Soil Structure	Improve soil structure and porosity, leading to better aeration and root penetration.	Limited Nutrient Range	Certain complex nutrients or trace elements may not be suitable for encapsulation in hydrogels.
Reduced Water Runoff and Soil Erosion	Reduce soil erosion and nutrient loss, preserving soil fertility and ecosystem health.	Application Logistics	Require specialized equipment or techniques. Ensuring uniform distribution throughout the field is challenging.

8. Recent Innovations and Research Advances

- **Nano-hydrogels**: Offer controlled delivery of water, fertilizers, and pesticides at nano-scale precision.
- **Bio-based sources**: Development of biodegradable hydrogels from banana peel, rice husk, guar gum.
- **Hydrogel encapsulation**: Embedding beneficial microbes or nutrients for dual action.
- **Field trials**: TNAU, IARI, and ICAR institutes report **yield increases up to 30%**, particularly under **aerobic rice**, **rainfed sorghum**, and **vegetables**.

9. Case Focus: Hydrogel Use in Karaikal and Aerobic Rice Cultivation

In coastal regions like **Karaikal**, where soil salinity and erratic monsoon affect crop performance, hydrogel application in **aerobic rice systems** improves **water retention and nutrient availability**. Studies show enhanced panicle numbers, spikelet fertility, and grain yield when hydrogels are integrated with **intercropping** and **mulching**.

This contributes to **doubling farmer income** through:

- Reduced irrigation costs.
- Increased productivity.
- Sustainable resource use.

10. Conclusion

Hydrogels provide a promising solution for water management in modern agriculture. Their capacity to absorb and release water gradually enhances **crop performance, soil health**, and **resource-use efficiency**. While challenges remain regarding cost and environmental sustainability, innovations in bio-based and nano-hydrogels offer pathways for eco-friendly, large-scale adoption. Hydrogels, when used judiciously and in conjunction with **integrated agronomic interventions**, can play a significant role in **climate-smart farming** and in achieving the national goal of **doubling farmer incomes**, especially in stress-prone ecosystems.

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Sea Ranching in India: Practices, Progress, and Prospects for Sustainable Fisheries

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Abstract:

Sea ranching is a sustainable method for restoring marine resources by rearing young marine animals in hatcheries and releasing them into the ocean to replenish natural populations. In India, the practice began in the 1980s under the leadership of CMFRI and has since expanded across Tamil Nadu, Kerala, Gujarat, and the Andaman Islands. Species such as prawns, pearl oysters, sea cucumbers, and lobsters have been successfully ranched. This technique supports biodiversity conservation, enhances depleted stocks, and provides livelihood opportunities for coastal communities. By combining aquaculture science with natural ecosystem restoration, sea ranching contributes to India's Blue Economy and Sustainable Development Goals. With proper hatchery production, release site selection, and community participation, sea ranching offers a practical, eco-friendly approach to rebuilding marine wealth and ensuring the long-term sustainability of fisheries.

Introduction:

Sea ranching is a technique for improving marine resources that involves raising young marine animals in hatcheries and releasing them into the ocean to maintain and replenish natural populations. In order to preserve and restore natural populations, sea ranching is a method of enhancing marine resources that entails rearing young marine animals in hatcheries before releasing them into the ocean. It is crucial for maintaining biodiversity, replenishing depleted stocks, and fostering sustainable coastal livelihoods. Sea ranching uses fisheries management and aquaculture principles to augment stocks while maintaining a balance between the preservation and use of marine resources. Sea ranching is another name for artificial recruitment. Aquatic species are raised in captivity (usually in hatcheries) until they reach a certain size or stage, at which point they are released back into their native marine habitat in an effort to enhance, restore, or maintain wild populations. Unlike aquaculture, there is no feeding or care after release the organisms grow and reproduce in the wild.

Sea ranching has been promoted as a key component of the expansion of India's marine fisheries by the Central Marine Fisheries Research Institute (CMFRI) and several of state fisheries departments. Abalone, clams, seabass (*Lates calcarifer*), lobsters (*Panulirus spp*.), sea cucumbers (*Holothuria scabra),* and other ranching species can flourish in India's diverse marine environments and vast coastline, which stretches over 11098.81 km. To restore overfished habitats and boost natural populations, experimental marine ranching projects were initiated in the late 1980s and early 1990s, primarily along the coasts of Tamil Nadu, Gujarat, and the Andaman Islands.

Sea ranching supports resource restoration, diversifies income for fishing communities, and increases fishery productivity—all of which support India's Blue Economy strategy and Sustainable Development Goals (SDGs). It helps reduce the fishing burden on wild species while preserving the environment's long-term stability. However, careful species selection, hatchery stock genetic control, and the active participation of local stakeholders are essential to the success of sea ranching. Therefore, sea ranching in India is a forward-thinking approach that supports the resilience and sustainable management of marine ecosystems by combining conservation with fisheries development.

History:

- ✓ **Ancient Roots:** Originated in the USA as early as **1870**.
- ✓ **Salmon Ranching:** Ranching of red and Pacific salmons in the Far East since **1964**, producing an additional **10,000–20,000 tonnes/year**.
- ✓ **Japan (1970s–1980s):** Pioneered large-scale ranching for **abalone, "kuruma" shrimp (*Penaeus japonicus*)**, scallops, sea bream, flounders (~45 species currently ranched).

- ✓ **Global Expansion (1990s):** Lobsters, abalones, sea cucumbers, groupers included; supported by advances in hatchery technology, tagging, and monitoring.
- ✓ **India (1980s–1990s):** Initiated by **CMFRI** and **MPEDA**, focusing on **green tiger prawn (*Penaeus semisulcatus*)**, sand lobster (*Thenus unimaculatus*), abalone, sea cucumbers, pearl oysters, and clams.

Types of Sea Ranching:

- **Enhancement Ranching:** Increase stock of overfished species.
- **Restoration Ranching:** Reintroduce species lost due to habitat destruction/overharvest.
- **Put-and-Take Ranching:** Release for short-term harvest.
- **Conservation Ranching:** Maintain genetic diversity/endangered species.
- **Commercial Ranching:** Release for later commercial harvest by owner/community.

Steps in Sea Ranching:

- **Selection of Candidate Species:** Commercial value, overexploited status, survival in wild.
- **Brood stock Collection & Hatchery Rearing:** Controlled spawning, larval rearing, nursery culture.
- **Marking/Tagging (optional):** Elastomer tags, coded wire tags, genetic markers.
- **Selection of Release Sites:** Suitable habitat, food, water quality, predator protection.
- **Acclimatization:** Gradual adaptation to site's environmental conditions.
- **Release into the Wild:** At juvenile/sub-adult stage during favorable seasons.
- **Post-release Monitoring:** Survival, growth, recruitment to fishery, genetic impacts.

Sea Ranching in India - Key Examples:

- ❖ **Prawn Ranching (1985):** Palk Bay and Gulf of Mannar.
- ❖ **Pearl Oyster Ranching (1985):** *Pinctada fucata*; over 10.25 lakh spat billions of larvae released off Tuticorin; population replenishment indicated by higher oyster density in later surveys.
- ❖ **Clam Ranching (1993):** *Meretrix casta*, *Anadara granosa*, *Paphia malabarica*; sites at Ashtamudi Lake & Munambam; fenced plots showed measurable retrieval and production.
- ❖ **Sea Cucumber Ranching (2002):** (*Holothuria scabra*); In Tamil Nadu & Lakshadweep.
- ❖ **Lobster Ranching (2003):** Vizhinjam & Tuticorin.
- ❖ **Abalone Ranching:** Experimental in Gulf of Mannar.
- ❖ **Cobia Ranching (2011):** Vizhinjam, Thoothukudi and Ramanathapuram.
- ❖ **Silver Pompano Ranching (2012):** Vizhinjam coast.
- ❖ **Grouper ranching:** Vizhinjam coast.

Sl. No	Sea Ranching	Species
1	Prawn Ranching	*Penaeus semisulcatus* - Green Tiger Prawn *Penaeus monodon* - Giant Tiger Prawn *fenneropenaeus indicus* - Indian White Shrimp
2	Pearl Oyster Ranching	*Pinctada fucata* - Akoya Pearl Oyster
3	Clam Ranching	*Meretrix casta* - Asian Backwater Clam *Anadara granosa* - Blood Clam *Paphia malabarica* - Yellow Clam
4	Sea Cucumber Ranching	*Holothuria scabra* - Golden Sandfish
5	Lobster Ranching	*Panulirus homarus* - Scalloped Spiny Lobster *Panulirus ornatus* - Ornate Spiny Lobster
6	Abalone Ranching	*Haliotis varia* - Common Ear Shell
7	Cobia Ranching	*Rachycentron canadum* - Cobia
8	Silver Pompano Ranching	*Trachynotus blochii* - Silver Pompano
9	Grouper ranching	*Epinephelus coioides* - Orange Spotted Grouper

Agencies Involved:

1. **ICAR–CMFRI (Central Marine Fisheries Research Institute):**
   Annual Reports contain detailed records of marine ranching programs across Tamil Nadu, Kerala, Gujarat, and Andaman.
2. **CIBA (Central Institute of Brackish Water Aquaculture):**
   Brackish water Finfish and Crustacean Ranching in Indian Estuaries.
3. **RGCA (Rajiv Gandhi Centre for Aquaculture, MPEDA):**
   Seed Production and Sea Ranching of marine water species and brackish water in India.
4. **PMMSY (Pradhan Mantri Matsya Sampada Yojana):**
   Marine Ranching Initiative under PMMSY - Government of India.
5. **State Fisheries Departments:**
   Tamil Nadu Fisheries Department, Kerala Fisheries Department, Gujarat and Andaman administrations publish local sea ranching project data.

Difference Between Sea Ranching and Aquaculture:

Parameter	Sea Ranching	Aquaculture
Growing location	Wild (sea)	Controlled farms/ponds/tanks
Feeding after release	No	Yes
Purpose	Stock enhancement/restoration	Commercial production
Ownership of stock	Common property	Private property

Advantages:

- Enhances depleted wild stocks with minimal energy/feed/labour costs.
- Supports biodiversity conservation.
- Provides socio-economic benefits to artisanal fishers.
- Uses natural environment for growth, avoiding intensive farming costs.
- Can be integrated with ecosystem-based fisheries management.

Conclusion:

The success of sea ranching requires:

- Large-scale seed production in hatcheries.
- Adequate nursery and transportation facilities.
- Selection of optimal release sites.
- Continuous monitoring of released and natural stocks.
- Institutional support and funding.

If implemented strategically, sea ranching can play a major role in sustainable fisheries, resource conservation, and livelihood improvement.

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CELLULAR AGRICULTURE: THE FUTURE OF THE FOOD

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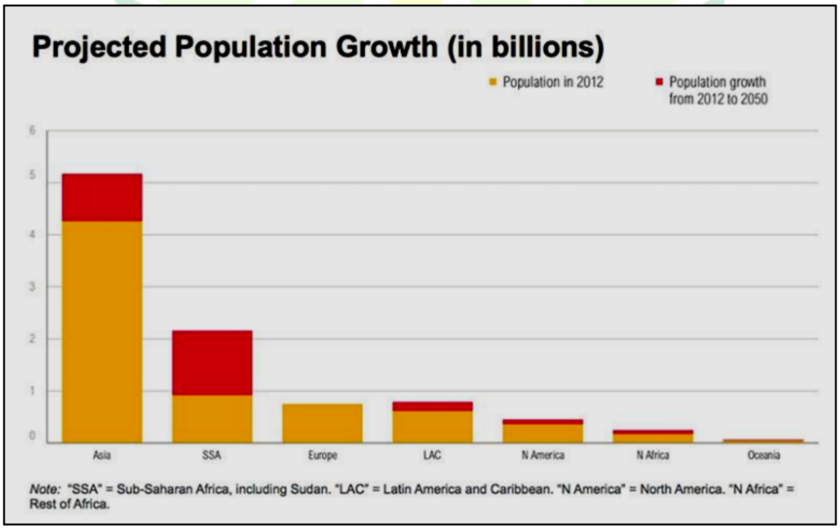
The human species progress has hugely impacted earth's environment and our climate. While technology is glorified and executed to be the cause of the climate change crisis, it contrasting nature of a situation, just as did for the ozone hole! The data brings out the fact that 26% of earth's ice-free surface is used for livestock farming, nearly 70% of all agricultural land. In addition, 27-29% of freshwater footprint is used for the production of animal products. Livestock farming is a top contributor to deforestation, land degradation, water pollution and desertification. Considering the fact that anticipated global demand for animal products to increase by 70% in 2050, it becomes extremely important to explore different ways to feed the growing population without destructing the earth's resources. Here we share interesting technologies in the area of food which holds promise to confront climate change challenges "Cellular Agriculture" being the one. Cellular agriculture and 3D food printing, the two new technologies that are expected to change the way people will source food from in near future. These technologies lead to animal-free, cultured and plant based versions of meat, milk, eggs and leather or in other words, they are milk without cow, eggs without hen and meat without animal. Over the last three years, several cellular agricultural startups have been created applying cellular agriculture to make a number of agricultural products and consumables. In fact, "Vegetarian Meat" based on plant sources is now available in India too. These alternate forms of growing meat have lead to saving many resources harmful to environment as well as created better acceptance by vegetarian segment of society from nutrition point of view and also reduction in cruelty towards animals. It offers significant promise for a more safe and diverse food system in a sustainable manner. If monitored and managed appropriately, cellular agriculture could allow humans to produce more food on less land than ever before while simultaneously tackling environmental problems.

UNDERSTANDING THE NEED

(a) Demand for animal food: The world population is growing at an alarming rate.



(Source: http://www.wri.org/sites/default/files/uploads/population_growth_0.jpg)

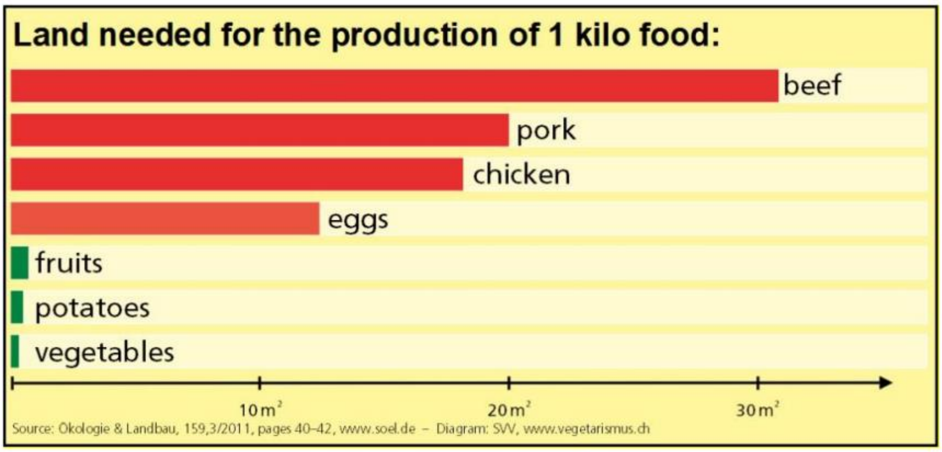
To feed millions of people and meet their dietary preferences, the livestock sector has been expanding continuously. Estimates indicate that for the last six decades the global meat production has risen three times and expected to reach 300 million ton by the year 2020. Part of the dietary preference is also due to rising affluence and urbanization. Thus, the exponential growth of livestock meat sector poses enormous challenges to sustainable food production. Overall, it seems the global demand for food production may increase by 70% (latest UN estimates) due to population growth. To sustain the livestock production, approx. 670 million tons of cereals are used as livestock feed annually, which is equivalent to over one-third of cereals consumed globally. This further constrains limited resources available to feed the enormous and rapidly growing population of the world. In addition to satisfying the hunger of a large population, there are many other pressing reasons for this paradigm shift. The key issue is to find lasting solutions to the environmental damage caused by the massive production of livestock animals.

(b) Global warming

Convincing scientific evidence points to the emission of methane (CH4) and nitrous oxide (N2O), by livestock animals. Navigating the numbers, it seems about 9 % of emissions from agricultural sector consist of Carbon dioxide, 35–45 % of methane and 45–55 % of nitrous oxide.

(c) Depletion of fresh water and land

The livestock sector uses huge quantities of water for producing feeds, rearing, and sanitation of animals. Estimates indicate that the livestock sector consumes over 8 % of global human water usage, e.g., in Brazil, the beef production requires 15,500 m3/t of water and chicken 3918 m^3/t. These numbers of massively converting fresh water into wastewater are alarming and pose a significant risk to human survival. Estimates indicate that water recycled from livestock manure may be responsible for 33% of global nitrogen and phosphorous pollution, 50% of antibiotic pollution, and 37% of toxic heavy metals found in freshwater. Approx 37% of pesticides have been found to end up in the water supply from livestock production.



(**http://www.vegetarismus.ch/info/eoeko.htm**)

Reports indicate that livestock farming takes up to 30% of earth's land surface. Of that, 70% of arable land is consumed in livestock farming. Some of the reports are truly alarming that indicate approx 70% of deforested areas in the Amazon rainforest are used as pastures, and a significant fraction of the remaining 30% is used to raise animal feed crops.

(d) Impact on human health

Reports indicate that 60% of human diseases and 75% of the emerging human diseases have origins in animal transmission For example, bovine spongiform encephalopathy (BSE), Swine and avian influenza have been found to be transmitted from animals. The intensification of livestock farming, will only worsen the fragile situation. Antibiotics are widely used to accelerate animal tissue growth, and keep them in good health till slaughter. The uncontrolled practice of using antibiotics for livestock animals has led to accumulation in the waterways and humans and is responsible for the significant rise in drug-resistant pathogen strains The World Health Organization considers this one of the biggest threats to global health.

(e) Animal well being

Animals are living beings full of emotions. They feel pleasure and pain just like humans. Any suffering inflicted upon them by humans for the sole purpose of raising animals for food is insensitive, unethical and vicious.

Massive animal farming often comes with disregard for their hygiene, safety, good health, and welfare. Animal farming consumes enormous land and water resources. Their high market demand often results in their torture both in the form of hormonal injections for biomass increase and saving money on their welfare, with the result that animal welfare is considered lowest priority and measures are reduced to a bare minimum. On paper, there may be nice documentation of animal welfare protocols. However, in reality, animal welfare is significantly ignored in factory farms. Animals are brutally treated before killing them for food.

(https://www.mirror.co.uk/news/uk-news/secret-film-exposes-chicken-factory-1338652)

As an example, "broiler chicken", optimized for obesity and rapid maturation is often reared in overcrowded conditions leading to immense suffering, fractured bones, and infections and so on. Worse at the time to transport to slaughterhouses, they are hung upside down in groups generating immense pain and wound. Furthermore, broilers are pushed into cramped transport containers and treated in inhumane conditions till their end of life. Despite standard guidelines to ensure animal welfare, the implementation is still weak and poorly. Animals are subjected to brutal amputations while alive. It is common for large meat producers to refuse public inspection of their farms and slaughterhouses. The world needs a credible alternative for meat supply ethically and safely.

A BRIEF INTRODUCTION

Cellular Agriculture is a multi-disciplinary branch of science encompassing biotechnology, medicine, and farming. It is a nascent technology that allows meat and other agricultural products to be cultured from cells in a fermentor or a bioreactor rather than harvested from livestock on a farm. It designs new mechanisms to produce existing agriculture products especially animal products from cell cultures rather than the bodies of living organisms. In other words, cellular agriculture is the technology with the use of which the real dairy products are produced without exploiting cows, eggs without hens and meat without having living animals slaughtered. While the main use of this technology has been for food applications, particularly *in vitro* or cultured meat, called 'clean meat', cellular agriculture can be used to create any kind of agricultural product, including those that never involved animals, to begin with, eggs, leather, milk, fragrances, gelatin and silk. Numerous animal-free protein products are hitting the shelves today, and with them are a variety of production methods. Cellular agriculture should not be mingled with another cutting-edge technology to produce plant-based meats. Plant-based meats aim to replicate the taste and texture of conventional meat. Cellular agriculture differs from the plant-based products like Beyond Meat's burgers, Hampton Creek's line of condiments and baking products and the varieties of nut-based milk in the market. Instead of making plant-based substitutes that try to impersonate the taste and texture of meat and dairy, cellular agriculture uses methods of tissue engineering to food production to create meat and dairy products that are molecularly similar to those made via conventional means. This can revolutionize the supply chain of animal products to continue to provide affordable and sustainable food and other materials to a growing population. Cellular agriculture allows us to make milk, eggs, meat, leather, fur, perfumes and other animal products but this dossier will majorly be focusing on clean meat. In recent years some cellular agriculture companies and non-profit organizations promoting the technology have emerged due to technological advances and increasing apprehension over the animal welfare and rights, environmental and public health problems linked with conventional animal agriculture.

TECHNOLOGY INVOLVED

(a) Historical

The origin of cell culture may be traced back to the late 19th century when Claude proposed that physiological systems of an organism can be maintained even after the death of the organism. This was quickly followed by the proof of the concept when demonstrated maintenance of embryonic chick cells in saline culture. Nearly a decade later, reported survival of blood cells outside the body. In 1907 Harrison demonstrated the maintenance of frog nerve cells in vitro. Five years later, Carrel established aseptic techniques for cell culture. By mid-1920s people were sensitized towards artificially maintaining the cells outside the body leading to the formation of ECACC for cell culture preservation. Between 1920 to 1930, differentiation of cells in vitro and fibroblast cell culture was reported. This gave impetus to the development of ATCC for developing standard techniques and preservation of cells. The culture of cells, preparation of antibodies and vaccine was actively followed between 1940 and 1950. Soon after, the first mouse fibroblast cell line and human cell line was developed. By mid-1950s a well-defined media for cell culture was established, the lifespan of human cells growing in vitro was defined leading to the development of first hybridoma cell line. Privatization of biotechnology took off in a major way leading to the production of first therapeutic protein in cell culture by Genentech in 1983. The developments in cell culture technology in the next three decades were rapid, widespread and made significant inroads in the public and private institutions. Concepts and methods of tissue engineering surfaced leading to the development of induced pluripotent cells and development of 3D bioprinting techniques.

(b) Cell culture fundamentals

For successful cell culture, one needs sterile work area ensured by pressurized air that passes through HEPA (High-Efficiency Particle Air Filter) filters, incubators, pure and sterile water, cold storage, microscopes and culture ware, the most common being specially treated polystyrene. The culture medium is prepared to provide food for the cells and maintain an optimal pH. In general, media is a combination of amino acids, fatty acids, sugars, ions, vitamins, cofactors inorganic salts and so on. Natural media that are used to grow cells in vitro may have plasma/serum or tissue extracts. In contrast, synthetic media is prepared artificially by adding nutrients, vitamins carbohydrates, salts etc., e.g., minimal essential medium, RPMI 1640 medium and so on. Cultures are mostly maintained at pH 7 – 7.4. Due to metabolic activities, the pH gets lowered over time and may result in cell growth inhibition. To slow down pH change bicarbonate based buffers are used in addition to maintaining the culture in 5% CO2 that serves as a gaseous buffer. Furthermore, a change in osmolality (i.e., number of dissolved particles in a fluid) can affect cell growth. Culture media are formulated in such a way that the osmolality is maintained around 300 mOsm. Growth requirements of cells demand supply of amino acids not synthesized by the cells. For example, glutamine is required by most cells in addition to essential amino acids like cysteine and tyrosine. To ensure that cell culture is clear of any infection, antibiotics (and in some instances) antifungal substances are added to the cell culture medium. Cell culture may be primary (i.e., the tissue is surgically removed and cultured in vitro) or derived from cell lines. Primary cell culture involves growing cells directly from the tissue. The other method is digesting the tissue by enzymes and creating a suspension of cells for culture. Primary cells have advantages of resembling closest to the source wherefrom cells were derived. However, loss of cells during enzymatic digestion, damage to the cell membrane and loss of viable cells, is a typical trade-off. The subculture of cells comes into picture when cells have grown to confluency and need to be transferred to another vessel for culture. Cells come with three basic morphologies: epithelial (cells adhere to the substrates and appear flattened / polygonal), lymphoblast like and fibroblast types. The culture of cells is highly technical and requires significant experience to maintain a right growth trajectory and aseptic conditions. Most of the cells have a finite lifespan. However, when cell get transformed into cell lines, they become immortal. In general, cell cultures provide a good model for studying the effect of drugs, the aging process, toxicity testing, and disease research and so on. Furthermore, they can also be used as factories to produce various chemicals, and proteins.

(e) Self-organizing method

With an aim to create highly structured meat, innovative approaches to self organized techniques are required. Back in 1912, researchers Alexis Carrel demonstrated the feasibility of keeping chick heart muscle alive in a petri dish using suitable culture medium and conditions. Further advances along the lines of self-organizing tissue grown in vitro, had to wait till 2002 when tissue engineering techniques were matured. In a landmark paper, the skeletal muscle explants from goldfish were reported to be grown artificially for a week, and interesting patterns of cell growth beyond the original explant were observed covering close to 80% of the surface area of the culture vessel. Authors of this work used a combination of fetal bovine serum, fishmeal extract, shiitake extract and maitake extract. Furthermore, the possibility of maintaining chicken muscle cells for a prolonged period of 8 weeks was also demonstrated. Though proof of the concept was made available, the bottleneck was an inability to develop a blood circulatory system within cells radiating out of the explants. Fast forwarding to 2018 and this still an unsolved problem. Sometime in future, if people can create a 3D mass of muscles with bones, cartilages and blood vessels self-organizing themselves at their natural positions, the science of in vitro meat will truly be path-breaking. (e) Scaffold-based technique: In the scaffold based technique, embryonic myoblasts or adult skeletal muscle cells are attached to a scaffold and then grown in a culture medium. Cells may be grown on collagen beads swimming in culture media or cells may be attached to a collagen meshwork and programmed to produce along with a specific track. Alternatively, in place of collagen other edible proteins may be used. In both the situations, the outcome is a three dimensional structure of meat. Cells may be further proliferated, differentiated and fused. Also, stem cells may be used to differentiate into various cell types and give a look of a natural meat. An ideal key property of a scaffold would be mechanical stretching and contraction that would program the cell growth along a predefined track. In the past, cytodex-3 micro carrier beads have been used as scaffolds in rotary bioreactors. However, in such beads, the flexibility and stretch ability are missing. In future, one could try various edible and stretchable polymers such as collagen, cellulose and so on.

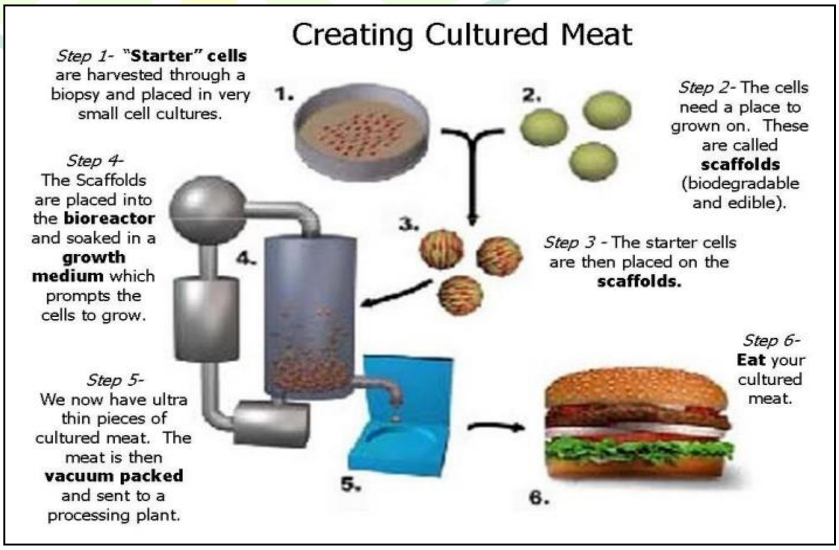
(c) Clean meat

The idea to create artificial meat may be traced to 1930s when Frederick E Smith wrote: "It will not be required to go through the time-consuming process of rearing a bullock to eat its steak. From one 'parent' steak of choice tenderness, it will be possible to grow as large and as juicy a steak as can be desired". Winston Churchill followed it up with his quote "Fifty years hence we shall escape the absurdity of growing a whole chicken to eat the breast or wing by growing these parts separately under a suitable medium. The technology used in the cellular agriculture is a blend of different disciplines viz. tissue engineering, synthetic biology and material sciences. The various research tools involved in cellular agriculture are cell lines, growth media, scaffold materials, 3D tissue systems and scaling technologies. Cells from a particular species and tissue type are assembled on a scaffold which aids the growth of cells with serum (food for the cells to feed on while they grow) in an environment that promotes growth. No living being is required for the production of either foodstuffs or materials. Significant six steps involved in the cellular agriculture may be seen in the diagram below.

(https://www.fdli.org/2018/02/update-laws-regulations-concerning-cell-cultured-meat-cellular-agriculture/)

(d) Steps involved

The ideal criteria for the cells to be used for cultured meat production include proliferativeb nature, immortality, and ability to grow independent of any surface and serum and tissue forming ability. These may be embryonic stem cells, adult stem cells or myoblasts. Stem cells proliferate at a high rate, but it is challenging to direct them to grow in a particular way. Fully developed muscle cells have complete development as a muscle but proliferate hardly at all. Therefore, cells like myoblasts are ideal which have already differentiated to an extent and also have the



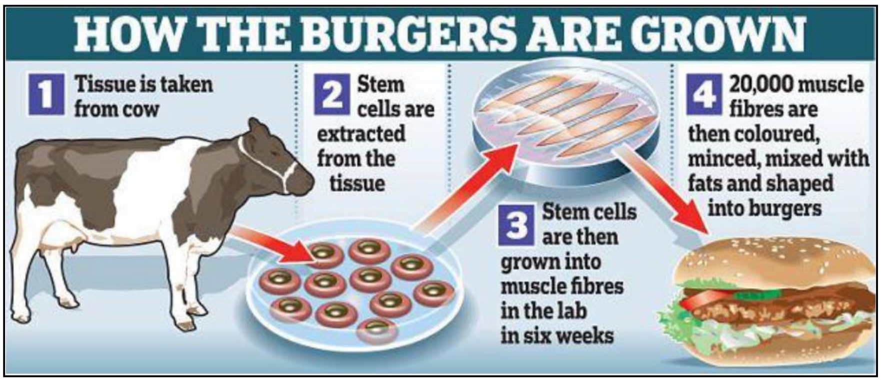
(Source: https://the-fringe.com/thread-in_vitro_meat (Cultured meat; manufacturing of meat products through "tissue-engineering" technology. By Stark Industries, 05-31- 2017)

ability to divide. The growth media uses a fetal bovine serum (FBS) for supplying cells with nutrients and stimulating growth factors. Bioreactors of increasing volume need to be created to make the whole process economically viable. To culture three dimensional meats, the cells are grown on a scaffold which ideally should be edible so that it is not required to be separated at the end of the process.

The process of developing cultured meat requires muscle cells and then applying a protein that kick-starts tissue growth. Genetic engineering is not required, although a method to extract muscle tissue from other tissues is needed. Once this is achieved, the extracted cells can be replicated to produce trillions of copies. As the process starts, meat is produced. In theory, it is anticipated calculation that two months of cultured meat production can end up in about 50,000 tons of meat from just ten pork muscle cells. Cultured meat is often produced as strips of muscle fibre. The culturing process occurs under desirable conditions inside a bioreactor explicitly designed for the purpose. Preservatives are added to prevent microbial growth. An alternative approach is to use the artificial circulatory system to distribute nutrients and oxygen, with the idea of producing cultured meat on a larger scale. Tissue engineering is a process wherein the tissues are made outside the body and is a relatively new scientific approach, with a focus on clinical applications such as growing skin for burn patients or organs for patients requiring organ transplantation. In our bodies, blood vessels carry nutrients and remove waste products from our tissues. This allows the tissues in our bodies to be quite thick, but if the vessels are absent, the cells do not have access to nutrients what they need to grow. In culture, tissues can only grow about 0.5mm thick without vessels. For growing organs for medical purposes, this is a problem. But for growing cultured meat, it is not. Cultured meat name is misleading in the sense that it gives a picture that the meat is produced in Petri plates and laboratories, but this is not true. The labs and petri plates may be involved in the initial stages, but scaled production will happen in large meat bioreactors or fomenters. It is unjustified to call it as lab-grown meat as well because there will be no labs involved in the commercial production. The name clean meat is the most accurate name not only because it is obtained without animal slaying but also because of the environmental benefits and decrease in food borne pathogens and drug residues. This is the term which industry has converged on and is likely to be used in India as well. There are therefore four main technology elements, which require specialized research and development: cell lines, cell culture media, scaffolds, and bioreactors. Each of these technology elements represents a significant area of opportunity for private industry and can draw on decades of advancement and investment in R&D.

(f) Stem cells

Stem cells are undifferentiated cells in organisms that divide to produce more stem cells. Two types of stem cells exist in multicellular organisms: embryonic stem cells that are found early in development and adult stem cells that are found in some regions of adult organisms like bone marrow, adipose tissue, and umbilical cord blood. A stem cell has the ability of self-renewal and also differentiate into specialized cells types, e.g., hematopoietic system. The science of stem cell culture and programmed differentiation has significantly advanced. Researchers have used background experimental data and hands-on experience in stem cell differentiation to grow myoblasts (musclecells) with intent to produce meatballs. Furthermore, satellite cells are used to form myotubes and myofibrils.

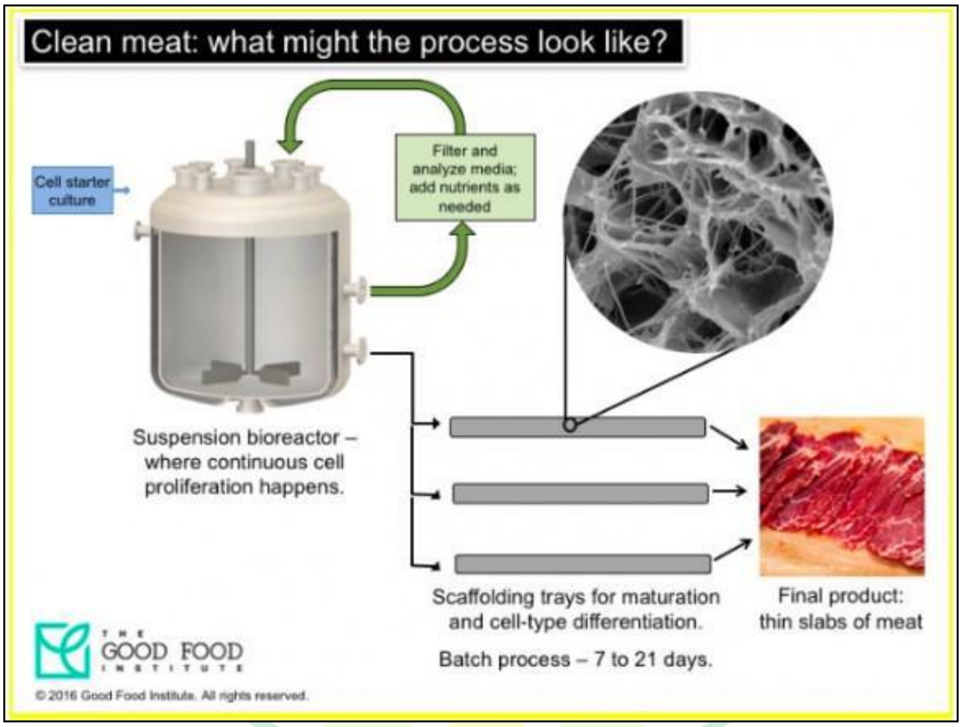


(http://www.dailymail.co.uk/sciencetech/article-3275913/Lab-grown-burgers-menu-2020-Scientists-set-company-make-stem-cell-meat-affordable-reality.html)

Adult stem cells are preferred sources for cultured meat generation due to ethical issues. Adult stem cells obtained from pigs and cattle have been proliferated successfully in vitro. Besides, adipose tissue-derived adult stem cells have also been used for cultured meat production, as they immortalize at high efficiency. Mature adipocytes have been found to dedifferentiate into multipotent cells with an innate property towards trans-differentiation into skeletal myocytes. Myosatelite cells are considered most suitable for culturing meat either alone or in combination with fat cells.

(g) Culturing meat in bioreactors

For the large-scale commercial production of cultured meat, a bioreactor based growth of cells is clearly a way forward. The key advantages of a bioreactor are a near-continuous suspension of cells, low fluid shear, and high output. The culture medium supplemented with serum and growth factors forms the foundation of cellular growth. Additives like esphingosine 1-phosphate and amino-acid rich mushroom extracts have been suggested for the serum-based media.



(http://www.gfi.org/clean-meats-path-to-commercialization)

Growth factors produced by the muscle cells themselves and other cell types help in further proliferation of the mass of the cells. As the cell proliferation enters differentiation and maturation phase, one may require a change in the culture media, as by-products and pH changes can slow down / inhibit the growth. Bioreactors are used for growing cells large scale under controlled conditions of temperatures, pH, oxygen levels, and nutrients and so on. Historically, bioreactors have been used to make pharmaceuticals, vaccines, or antibodies. With the evolution of needs, bioreactor technologies have evolved too. Recently, rotating bioreactors were used for the production of skeletal muscle tissue.

Myoblasts have been used for culturing meat avoiding atrophy that can result in a large-scale uncontrolled growth of cells. Differentiation and proliferation of cells can be induced by mechanical, electromagnetic, gravitational, and fluid-flow methods. The repetitive contraction and relaxation can enhance the length of skeletal muscles by at least 10%. One of the pressing unmet need for large-scale production of in vitro meat is to lower cost of culturing the cells. The serum is highly expensive and needs to be used in substantial proportions to ensure significant cellular growth. To find low-cost alternatives, people have used serum-free media. An interesting recent development has been to use Cyanobacteria as a potential food source for cell growth. Cyanobacteria are photosynthetic bacteria with a protein content of up to 70% dry weight and can be easily cultured for large scale.

GLOBAL TRENDS

Estimates of when cellular agriculture products can reach grocery shelves are difficult to make, as their availability will depend on successful research and how well the regulations support them. With major advancements from a technology aspect, however, it is hoped that consumers will get to enjoy cultured meat products in the predictable future. Lab-grown or "cultured meat" could be a bridge between real meat and plant-based products. 30% of the calories consumed globally by humans come from meat products including beef, chicken, and pork. The meat industry has evolved into a complex global business that involves farms, middle-men, processing and storage centers, transportation, slaughterhouses and more. The commercial meat industry faces a rising tide of challenges in the form of business, ethical and environmental concerns. Meanwhile, start-ups using technology to engineer meat in labs or manufacture from plant-based products are rising in getting recognized and popularity. Meatless food products from beef-free burgers to pea based shrimp intimidate the future of the meat giants. There are two non-profits funding and accelerating the research and commercialization of cellular agriculture: The Good Food Institute is donor-funded non-profit, which works to accelerate research and commercialization in this area. They work directly with universities and scientists to identify, fund, and write proposals for high-value projects, and are already working with a few labs in India. New Harvest is another research institute dedicating funds and efforts for the advancement of cellular agriculture. This donor-funded organization intends to solve major challenges coming on the road to commercialization that include finding a cost-effective medium for cell nutrition and developing an optimized bioreactor design (the machines in which cultured meat will be grown in larger quantities once production moves from the R&D stage in labs).

Some companies are competing and looking for avenues to launch their animal-free products first in the market of meatless space. Startup companies such as Hampton Creek and Memphis Meats hope to be the first ones to bring lab-grown meat to store shelves in 2018 and 2021 respectively. Taking a different approach, Yuki Hanyu, founder of Tokyo-based Integriculture and non-profit Shojinmeat Project, is working to acclimate future generations to a meatless future through open source tech. Hanyu is providing Japanese high school students access to high-tech heated boxes that allow them to culture animal cells at home and grow them into meat-like products.

San Francisco based Memphis Meats produces meat from self-replicating cells, thereby resulting in producing meat that is an "animal-based" product but avoiding the need to breed, raise, and slaughter huge numbers of animals. The company made public its first synthetic meatball in 2016 and followed up with the world's first cell-cultured chicken and duck earlier this year. Memphis Meats was not the first company to explore lab-grown meat products. In fact, Dr. Mark Post, a Netherlands-based researcher, produced the world's first lab-grown burger in 2013, in research originally financed by Google's co-founder Sergey Brin. This initiative resulted in Mosa Meat, which aims to bring *in vitro* meat to market in the future.

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Precision IoT-Enabled Laser Sensor Device for Depth Measurement in Drone Spray Testing with a Patternator

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Abstract

Manual measurement of the spray volume of the patternator test tubes during testing of the drone is time consuming, prone to human error, and has no provision to store data. To address these limitations, **hand-held, and user-friendly IoT-enabled water depth measuring device** was developed. The device consists of **time-of-flight (ToF) laser sensor** paired with a **Wi-Fi-enabled microcontroller, trigger button**, LCD and battery (5 V). It measures water depth accurately and estimate the corresponding spray volume in an individual test tube. Through IoT integration, the device not only displays readings locally but also sends them in real time to a **cloud,** where data can be stored, accessed remotely, and used for further analysis. The device was validated using cylindrical test tubes, achieving accuracy within ±4% error compared to standard manual method. By merging accurate sensing with IoT connectivity, the system delivers not only reliable measurements but also the convenience of real-time data access and storage. The device will be further enhanced to support **dual functionality** through the integration of a **touch display** enabling users to switch between water level measurement and **distance measurement**.

Introduction

Drone Technology is undergoing a massive Tranformantion in Various sectors like, Defence, Logistices and Health, Agriculture, Infrastructure and Industry or Environment and Forestry Drones play a vital role in transforming Indian agriculture by enabling precision farming and efficient resource management. They help farmers monitor crop health, assess soil conditions, and detect pest or disease infestations through aerial imaging and sensors. Drones also make spraying fertilizers, pesticides, and nutrients faster, safer, and more uniform, reducing chemical use and labor costs. In a country like India, where timely farm operations are crucial and manpower is often limited, drone technology offers a modern, data-driven approach to increase productivity, ensure sustainability, and support small and large farmers alike.

India Drone (UAV) Market: Size & Forecast

The drone market in India is growing faster than ever before. Experts believe it will reach a massive US$ 13 billion by 2030, up from just US$ 2.71 billion in 2022. That’s a huge jump, showing how quickly drones are becoming an important part of our everyday lives and industries. The market is growing at a strong pace of **21% annual growth** (CAGR), meaning the market roughly doubles every 3–4 years. As of March 2024, India already has over 200 drone startups working on new and exciting ideas. These startups are building drones for many different uses — from spraying pesticides on farms and delivering packages, to monitoring construction sites, mapping land, and helping in disaster management. This innovation is helping India move closer to becoming a global leader in drone technology.

Why Agricultural Drone?

Global agriculture is facing a critical challenge: up to 40% of all crops are lost to pests and diseases annually, resulting in economic damages exceeding $290 billion. Compounded by rising operational costs, climate change pressures, and increasing demands for supply chain traceability, the need for sustainable and efficient farming. Unmanned Aerial Vehicles (UAVs) offer a transformative advantage. Modern agriculture is increasingly relying on drones to collect, process, and analyze farm data in real-time. By integrating technologies such as GPS (Global Positioning System), GIS (Geographic Information System), and advanced AI (Artificial Intelligence), drones are enabling farmers to make smarter, faster, and more precise decisions.

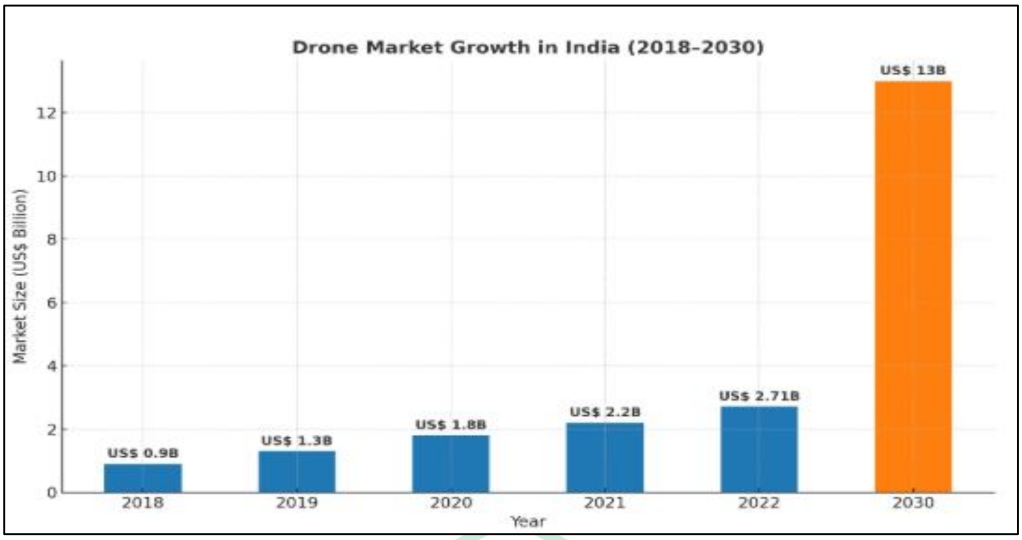

Fig 1: Drone market size trend in India from 2018-2030

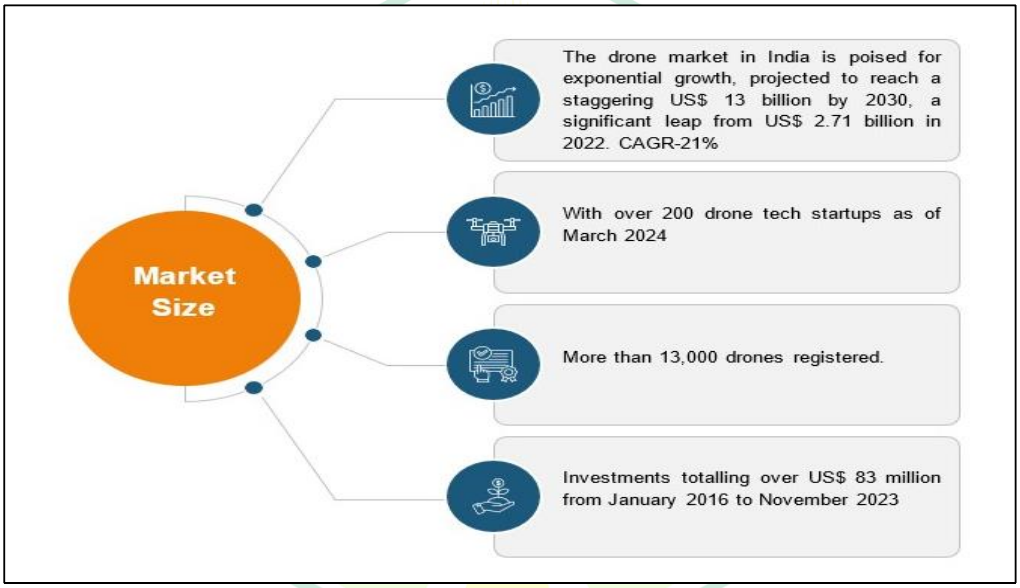

Fig 2: Details of drone market size in India

Applications of drone in Agriculture

Land Mapping and Surveying: The initial step in drone-based farming is creating a detailed map of the area to be monitored. Flight planning software helps define automated paths for drones, capturing images from multiple angles and tagging them with precise coordinates. This method gathers comprehensive information on various farm parameters much faster than traditional ground-based surveys.

Soil Monitoring: Maintaining soil health is essential for productive farming. Drones equipped with multispectral sensors can detect light wavelengths unique to different soil conditions. AI-powered software then analyzes this data to provide insights on soil fertility, nutrient levels, erosion risks, and readiness for seasonal crops. This approach allows continuous, year-round monitoring and proactive soil management.

Planting and Seeding: Drones are now being used to plant seeds on a large scale, using data on climate, soil, and terrain to optimize the process. Automated drone seeders offer a safe and efficient solution, especially in challenging or hazardous landscapes.

Irrigation Management: Drones equipped with sensors and other monitoring technologies can assess soil moisture levels accurately. This enables precise water distribution, reduces wastage, and helps identify irrigation issues such as leaks or poor drainage patterns, ultimately conserving water.

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Crop Health Monitoring: High-resolution drone images allow farmers to track crop growth, density, and detect early signs of disease or stress.

Crop Spraying: Drones can automate the application of fertilizers, pesticides, and water-soluble chemicals. Equipped with sensors and misting technology, drones ensure uniform coverage while navigating obstacles efficiently.

Damage Assessment: Drones can rapidly record crop damage from pests, diseases, floods, or weeds. Early detection helps farmers minimize losses, restore affected areas, and accelerate insurance claim processes during disasters.

Livestock Management: Drones are also useful in monitoring livestock, detecting sick or stray animals, and even guiding herd movements. The sound of a drone hovering above cattle can gently direct them, preventing crop damage and improving animal safety.

Spraying Drones in Agriculture

Spraying drones are becoming increasingly popular as they can distribute pesticides, fertilizers, or water evenly over the crops, reducing manual labor and saving time. This not only increases productivity but also minimizes chemical exposure for farmers and ensures more precise application of resources.

a) Drone Spraying in a field

b) Spraying Drone Components

Fig. 3 Drone used for spraying in agriculture

Drone performance testing

Drone testing is essential to ensure the safety, efficiency, and accuracy of agricultural drones before their use in the field. Proper testing helps evaluate flight stability, payload capacity, spraying uniformity, and droplet distribution — all critical factors for effective crop spraying. One of the biggest challenges in drone spraying has always been the **measurement of spray uniformity**. The patternator plays a key role in this process by measuring the spray pattern and distribution of droplets released from the drone's nozzles. It helps determine whether the spray is uniform across the swath width and identifies areas of over- or under-application. This data allows for calibration and optimization of spray parameters such as nozzle type, pressure, and height, ensuring precise application of agrochemicals and minimizing wastage and environmental impact.

Drone spray testing patternator

Drone spray patternator was developed which consists of 180 test tubes to collect spray droplets. The patternator measures 5 m in length and 3 m in width, incorporating 192 fabricated V-channels. To facilitate mobility, the unit is equipped with six wheels, allowing it to be easily moved from the parking shed to the experimental site. Each V-channel has been fabricated according to standards to prevent water from spilling into adjacent channel. They are supported by vertical sheets 10 mm in height and 1.6 mm thick and are inclined at 30° from the vertical support. The center-to-center distance between consecutive V-channels is 26 mm. A total of 180 transparent cylindrical glass tubes, each with a capacity of 200 ml, are used to collect water from 180 effective V-channels. Each tube is 25 mm in diameter and 560 mm in length and are securely housed within an aluminum rectangular frame. The V-channel dimensions are 25mm in width, 28 mm in depth, and 1.6 mm in thickness with 3.2 mm radius of curvature. They are supported by vertical sheets 10 mm in height and 1.6 mm thick and are inclined at 30° from the vertical support.

Fig. 4 Patternator test set-up used for drone testing

Each V-channel directs water flow into the corresponding glass tube for collection and analysis. A flip mechanism has been integrated to control water flow, allowing individual V-channels to either allow or stop the flow of water in cylindrical tube. Additionally, a handle assembly is provided to conveniently empty all tubes after each experiment. To protect the setup from direct sunlight and rain, a shed has been constructed with dimensions of 6.5 meters in length, 4.5 meters in width, and 3 meters in height. The shed is enclosed on three sides and covered with diamond-patterned white polycarbonate sheets on the top and sides. This setup will be used to evaluate spray uniformity at varying drone heights and discharge rates. Recording the volume in each tube is **labor-intensive, time-consuming, and error-prone.** Each test can take 20–30 minutes, making repetitive trials impractical and reducing accuracy. To solve these limitations, we have developed a Hand-held, IoT-enabled and user-friendly water depth measuring device. This compact, user-friendly tool is designed to replace the slow manual measurement process with fast digital accuracy.

Fig. 5 Manual measurement of volume of water collected in a test tube of patternator

Advancement from manual to digitalization:

IoT-enabled hand-held laser sensor-based depth measuring device

This device integrates a **VL53L1X laser distance sensor,** which measures the water level inside transparent test tubes with precision. The operation is simple: a **push-button trigger** activates the sensor, instantly determining the distance to the water surface. An **ESP8266 microcontroller** then processes this input, calculating both the **water height and volume** using predefined calibration values. The results are displayed in real time on a **16×2 LCD screen.** In addition, the device transmits the measured data wirelessly to a **web server**, enabling **cloud-based real-time logging, storage, and visualization.** By automating the measurement and recording process, this IoT system eliminates **human error**, enhances **data consistency**, and significantly reduces the time required for analysis. Overall, this compact and portable device provides a **practical solution for precision agriculture,** while also holding strong potential for applications in **research laboratories** where accurate volumetric measurement is essential.

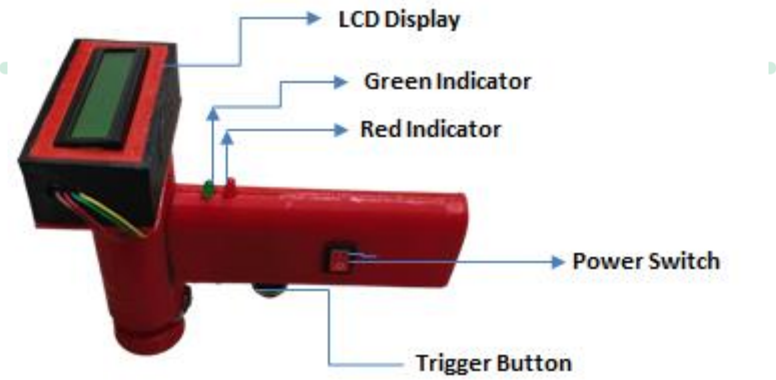
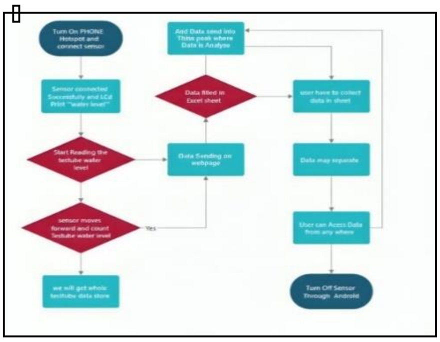
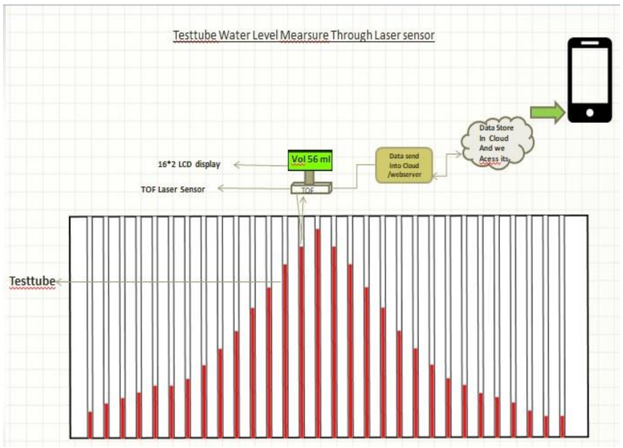


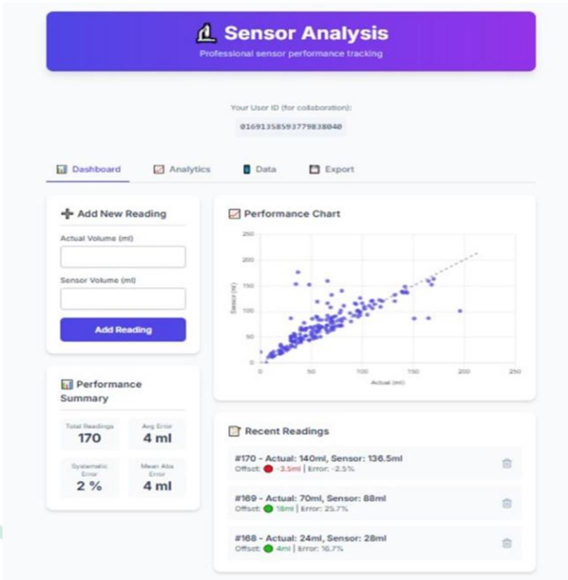
Fig. 6 Handheld IoT-enabled laser sensor device

<u>**Measurement procedure:**</u>



- **Activate System:** The system powers on and the laser sensor becomes active.
- **Measure water depth:** A button press triggers the laser to measure the distance to the water surface and calculates the water volume through formula in code.
- **Show Reading:** The calculated water level is displayed on the screen.
- **Send to Cloud:** The microcontroller sends the data wirelessly to a cloud server.
- **Access Data:** The data is stored and can be viewed on a phone or computer for analysis



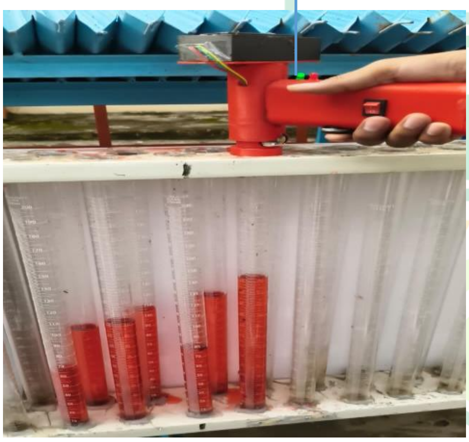


Real time data analysis

Activation and data Capture

First, the handheld device is powered on. To capture data, a user presses a trigger button, which activates a VL53L1X laser distance sensor. This sensor measures the distance to the surface of water in a test tube.

Onboard processing



Once the sensor captures the actual distance data, an ESP8266 microcontroller using pre-programmed formulae, processes this raw data to calculate volume of water in milliliters (mL).

Wireless transmission to the cloud- The ESP8266 microcontroller, which has built-in Wi-Fi capabilities, connects to the internet simultaneously, as the result is displayed on the screen; the microcontroller sends the calculated data wirelessly to a web or cloud server.

Cloud storage and analysis- This allows the information to be securely saved and accessed from anywhere using a phone or computer. The data can then be used for real-time analysis, visualization on a dashboard with charts, and logging, as shown in the sensor analysis application.

Conclusions: -

This article presents the development of a **handheld IoT-enabled laser sensor device** designed to measure water volume in drone spray patternator experiments with accuracy and efficiency compared to conventional manual methods. Traditionally, in Drone spraying testing a record of water collected in test tubes of a patternator by visual inspection and manual noting, process is time-consuming, labor-intensive, and prone to human error. The proposed system overcomes these limitations by integrating a **VL53L1X laser distance sensor**, It accurately measures the water level inside transparent cylindrical test tubes. Measurement is initiated by a **push-button**

trigger, making the process simple and user-friendly. The captured distance data is processed by an **ESP8266 microcontroller**, which calculates the water height and volume using pre-calibrated formulas. The results are displayed instantly on a **16×2 LCD screen**, while simultaneously being transmitted to a **cloud server** for real-time logging, storage, and visualization. The IoT-based device ensures **reliable, repeatable, and error-free measurements**, enabling researchers to perform multiple tests with greater consistency and speed. By reducing time and effort, the system supports the goals of **precision farming, digital agriculture, and data-driven decision-making.** Beyond agriculture, the device also has potential applications in **laboratories and** precise liquid or volume measurement requiring precise volumetric measurements.

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Alternative Protein Sources and Agri food Innovations

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Abstract

The world's growing population and increasing demand for sustainable food systems have driven innovation in alternative protein sources and agri-food technologies. Alternative proteins from plants, fungi, algae, insects, and lab-grown products offer eco-friendly and nutritious alternatives to traditional animal products, using fewer resources, emitting less greenhouse gases, and promoting food security. Agri-food innovations like precision farming, biotechnology, and smart processing technologies are enhancing productivity, improving supply chain efficiency, and reducing post-harvest losses, supporting farmers by diversifying production systems and creating new market opportunities. However, challenges like consumer acceptance, high production costs, regulatory barriers, and lack of infrastructure hinder large-scale adoption. This article explores the potential, benefits, and limitations of alternative protein sources and agri-food innovations, paving the way toward a healthier and more sustainable global food future. In short, alternative proteins and agri-food innovations are transforming our food systems, offering sustainable and resilient solutions for the future.

Keywords

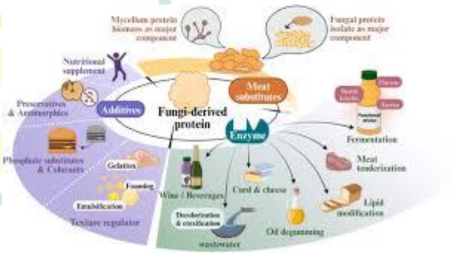
Sustainable nutrition, Food security, Biotechnology in agriculture, Novel protein production, Environmental sustainability.

Introduction

Alternative proteins are sustainable food sources that mimic traditional animal products, benefiting consumers and farmers by diversifying agriculture and strengthening rural economies. Promoting research and innovation in alternative proteins can help build a more resilient and sustainable food system, enhancing long-term food security and generating value for agricultural communities.

Alternative Protein Sources

Fungal-Derived Proteins: Fungi are packed with protein (10-63%), fiber, and essential amino acids, making them a great meat substitute (Perez-Montes et al., 2021; Mingyi et al., 2019). Mycoprotein, derived from filamentous fungi, is a popular choice and has been designated as Generally Recognized as Safe (GRAS) by the U.S. Food and Drug Administration (FDA) for certain fungal strains like *Fusarium venenatum, Monascus purpureus, Aspergillus oryzae, Neurospora intermedia,* and *Rhizopus oryzae.*



Source: ScienceDirect.com

Algae-Derived Proteins: Microalgae like Chlorella are rich in essential amino acids (Koyande et al., 2019), while macroalgae (seaweed) have been a part of our diet for centuries and have been approved by the European Food and Safety Authority (EFSA) (Banach et al., 2020). Algae contain high protein content, dietary fibers, and omega-3 fatty acids (Baune et al., 2022).

Source: PlantFusion

Source: Food Navigator

Insect-Based Proteins: Insects are a great source of protein (40-70%), healthy fats, and essential nutrients (Gorbunova and Zakharov, 2021). They're also environmentally friendly, producing fewer greenhouse gas emissions (Akhtar and Isman, 2018).

Plant-Based Proteins: Plant-based proteins like soy, seeds, legumes, and nuts are gaining popularity for their health benefits and sustainability (Kumar et al, 2023). Research indicates that plant-based diets can reduce the risk of chronic illnesses like heart disease, diabetes, and certain cancers (Wood and Tavan, 2022).

Source: Plant Based News

Protein Source	Protein Content	Environmental Impact
Fungal-derived	10-63%	Low water usage, low land use
Algae-derived	70%	High
Insect-based	40-70%	Low greenhouse gas emissions, low land use
Plant-based	20-50%	Low water usage, moderate land use

Agri food innovations

Technological advancements are transforming the agri-food sector, enhancing food product value and meeting consumer expectations. The sector is converging with industries like pharmaceuticals, biotechnology, and nanotechnology, creating new opportunities. This convergence is driven by the blending of technologies, markets, and knowledge from previously distinct industries, removing boundaries and creating new business segments. The adoption of information and communication technologies (ICTs) is another major trend in the agri-food system. Drones, sensors, big data analytics, and digital platforms are revolutionizing production monitoring, food ordering, and supply chain management. Additionally, biotechnological tools are applied to crop protection, food preservation, and functional food development, while nanotechnology enhances packaging and food safety. The future of agri-food innovations looks promising, with a focus on sustainability and circular economy principles. Smart farming, automation, and robotics are expected to dominate the next phase of agricultural evolution. These innovations will not only enhance food production but also contribute to environmental sustainability and meet diverse consumer needs (Bröring, 2005).

Technology	Description	Benefits
Precision farming	Use of drones, sensors, and GPS technology	Increased crop yields, reduced water usage
Biotechnology	Genetic engineering, gene editing	Increased crop resistance, improved nutritional content
Smart processing	High-pressure processing, pulsed electric field processing	Improved food safety, increased shelf life

Benefits of Alternative Protein Sources and Agri-Food Industries

- Healthier Fats and Fiber: Plant-based and insect proteins reduce heart disease risk.
- Environmental Sustainability: Alternative proteins require less land, water, and produce fewer greenhouse gas emissions.
- Food Security: Meeting growing food demand with sustainable options.
- Economic Opportunities: New business ideas and innovations in the food sector.

Challenges of Alternative Protein Sources and Agri-Food Industries

- Consumer Acceptance: Lab-grown proteins and insect-based foods face cultural and taste barriers.
- High Production Costs: Expensive production makes alternative proteins less accessible.
- Regulatory Barriers: Lack of clear regulations and labeling standards slows sector growth.
- Infrastructure Gaps: Limited storage, transportation, and processing infrastructure reduces efficiency.

Conclusion

Alternative protein sources and agri-food innovations are transforming our food systems, offering sustainable and resilient solutions for the future. With continued investment in research, innovation, and public-private partnerships, we can address global hunger and environmental degradation, ensuring a secure food future for generations to come.

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Morden Agriculture Cultivation Techniques, Objective, Types of Modern agriculture

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Introduction

Agricultural technology means using modern tools, machines, and scientific methods to grow crops and raise animals more easily and efficiently. In the past, farmers used animals like oxen and horses to plough fields and harvest crops. Today, those jobs are done by tractors, harvesters, and other machines. During the 19th century, machines like portable engines and threshers became common. In the 20th century, farming improved even more with the invention of synthetic (man-made) fertilizers and pesticides. Tractors, airplanes for spraying crops, and other machines helped farmers grow more food faster. The 20th century brought major progress in farming methods. Farmers started using synthetic fertilizers and pesticides to improve crop yields and protect plants. New types of machines, such as mass-produced tractors, also became common, making farm work faster and easier

Morden Agriculture

The country could achieve self-sufficiency in food grain production by using Modern methods of agriculture using better quality of seed, proper irrigation and adequate Supply of plant nutrients by using chemical fertilizers and control of pests and diseases in Crop plants by using pesticides. It has also involved modern cultivation practices using Tractors, combine harvesters and tube wells for irrigation. Rapid growth in food grain Production from using seeds of high yielding variety is termed as Green Revolution. Several farmers around the world work using the most innovative practices and growing techniques for the production of food, fuel, and fibre.

Objective of Modern Agriculture

The main objective of modern agriculture is to increase food production in a sustainable and efficient way by using advanced technologies and scientific methods. It focuses on:

1. Improving crop yield and quality
2. Ensuring food security for a growing population
3. Efficient use of natural resources (soil, water, energy)
4. Reducing environmental impact (less pollution, soil conservation)
5. Enhancing farmers' income through better practices and market access
6. Adopting modern technology like AI, drones, and biotechnology
7. Building climate resilience in agriculture

Types of Modern Agriculture –

1. **Precision agriculture (PA):** is a management strategy that gathers, processes and analyzes temporal, spatial and individual plant and animal data and combines it. Think of this like "smart farming." Farmers use special tools, sensors, and machines to collect detailed information about their crops and animals — like how much water a field needs or whether an animal is healthy.
2. **Vertical farming**: Vertical farming is an innovative agricultural method that revolutionizes traditional crop production by growing plants in vertically stacked layers or vertically inclined surfaces within controlled indoor environments. This modern farming technique maximizes food production per unit of land by utilizing all three dimensions of space, allowing farmers to grow significantly more crops in smaller areas compared to conventional horizontal farming.
3. **Hydroponics:** Hydroponics is a special farming technique, where farmers do not use soil to grow plants; instead, the plants are grown in a nutrient-rich water solution. This method allows for year-round production, and due to complete water farming, the method has significantly reduced water usage compared to traditional soil-based farming.
4. **Organic farming:** Organic farming in modern agriculture emphasizes sustainable practices that protect soil health, biodiversity, and human well-being. It avoids synthetic fertilizers, pesticides, and genetically modified

organisms, instead relying on natural compost, green manure, crop rotation, and biological pest control. This method enhances soil fertility, conserves water, and reduces pollution, making farming more eco-friendly.

5. **Aquaponic:** is the combination of Aquaculture (raising fish) and Hydroponics (soilless plant cultivation) in a symbiotic environment (i.e. mutual benefits). This farming method works as one combined system where fish and plants support each other. The waste produced by fish becomes a natural source of nutrients for the plants, while the plants, in return, purify and refresh the water for the fish. This creates a balanced environment that boosts productivity in an eco-friendly and sustainable way.
6. **Aeroponics:** is a modern way to grow plants without using soil. Instead of planting them in the ground or in water (like in hydroponics), the plant roots are suspended in the air, and a nutrient-rich mist is sprayed directly onto the roots. The word "aeroponics" comes from two Greek words. "aer" meaning air, "ponors" meaning work or effort even though there's no soil, plants still get everything they need—water, nutrients, and oxygen—through the mist. It's actually a type of hydroponics, because it uses water to feed the plants.

This method is:

- Super clean
- Uses less water
- Helps plants grow faster
- Great for small spaces or indoor farming

7. **Genetic engineering:** is a farming technique where crops are designed. This is engineering is done to make them strong against challenging environmental conditions. This farming technique offers high crop yields, although there is concern regarding ecological and ethical approach, which requires careful consideration and management.
8. **Drones:** are becoming highly valuable in modern farming as they help conduct aerial mapping, track crop conditions, and carry out precise spraying of fertilizers and pesticides. Their use minimizes manual labor, cuts costs, and allows farmers to respond quickly, resulting in better crop productivity.
9. **Agriculture sensors-** These sensors deliver live information about soil moisture, temperature, and nutrient status. With this data, farmers can adjust their farming practices, maintain ideal conditions for plant growth, and utilize water and fertilizers more efficiently.
10. **Artificial intelligence (AI)** AI supports agriculture through data-driven predictions and decision-making tools. It can analyze large datasets to forecast weather changes, identify potential pest threats, and suggest effective farming strategies. For instance, AI can warn farmers of a likely pest attack in advance, helping them act proactively and reduce crop damage.
11. **Biotechnology -**Biotechnology in modern agriculture enhances crop productivity and sustainability by using advanced scientific methods. It helps develop pest-resistant, drought-tolerant, and high-yield varieties, reducing dependency on chemicals. Techniques like genetic engineering, tissue culture, and molecular breeding improve crop quality, disease resistance, and shelf life, ensuring food security and environmental protection.
12. **Smart irrigation system** -Smart irrigation systems in modern agriculture use sensors, weather data, and automated controls to supply water efficiently. They monitor soil moisture and crop needs, ensuring precise irrigation while reducing wastage.

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Understanding Ant Behavior After Rainfall

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Introduction

The sudden appearance of large black ants after rainfall is one of the most commonly observed insect phenomena worldwide. These "big black ants" are typically **carpenter ants** (genus *Camponotus*) or other large ant species, and what you're witnessing is most likely their **nuptial flight** - a synchronized mating event that is specifically triggered by rain and associated environmental conditions. This dramatic emergence involves winged reproductive ants (alates) that have been developing inside the colony for weeks or months, waiting for the perfect conditions to take flight.

Identification:

Carpenter Ants (*Camponotus* species)

- Size: 6-13 mm for workers, up to 25 mm for queens
- Color: Typically black, sometimes with reddish or brownish tones
- Characteristics: Large mandibles, heart-shaped head when viewed from above
- Habitat: Wood (though they excavate rather than eat it)

Other Large Black Ant Species:

- *Lasius niger* (Black garden ant) - Common in many regions
- Various *Formica* species
- Regional species that vary by geography

The ants you see emerging after rain typically include:

- **Winged queens** (gynes) - Large, with wings, future colony founders
- **Winged males** (drones) - Smaller than queens but larger than workers, with wings
- **Worker ants** - Wingless, helping the alates exit the nest

Why Ants Emerge After Rain: The Complete Explanation

1. Nuptial Flight Triggering

Rain serves as the primary environmental trigger for ant nuptial flights (mating flights). The emergence you're seeing is a carefully timed reproductive event:

Humidity Requirements:

- Winged ants (alates) have delicate bodies and wings that are susceptible to desiccation
- High humidity following rain (often 70-90%+) prevents water loss during flight
- Moisture in the air allows ants to fly longer distances without dehydration
- Post-rain humidity ensures that queens can survive long enough to establish new colonies

Soil Softening:

- Rain softens the hard, compacted soil
- Newly mated queens must dig into the ground to establish their founding chambers
- Soft, moist soil is exponentially easier to excavate than dry, hard soil
- Without softened soil, many queens would die from exhaustion before completing their nests

Barometric Pressure Changes:

- Ants are highly sensitive to atmospheric pressure changes that precede and accompany rainfall
- Dropping barometric pressure signals approaching favorable conditions
- This serves as an "early warning system" allowing colonies to prepare for emergence

Temperature Moderation:

- Rain typically cools the air to moderate temperatures (20-25°C is often ideal)

- Cooler temperatures reduce energy expenditure during flight
- Prevents overheating of the large-bodied queens during their maiden flight

2. Synchronized Mass Emergence Across Colonies

One of the most remarkable aspects is that multiple ant colonies in an area release their alates simultaneously on the same day or evening after rain:

Predator Satiation Strategy:

- By emerging in vast numbers all at once, ants overwhelm their predators
- Birds, spiders, wasps, and other predators can only eat so many ants
- This ensures a significant percentage of reproductives survive despite heavy predation
- If colonies released alates sporadically, predators could eliminate nearly all of them

Genetic Diversity:

- Synchronized flights from multiple colonies ensure that males and females from different colonies intermingle
- This promotes outbreeding and prevents inbreeding
- Genetic diversity strengthens future colony health and adaptability

Environmental Synchronization:

- All colonies in a region respond to the same environmental cues (rain, humidity, pressure, temperature)
- This natural synchronization happens without direct communication between colonies
- Some research suggests colonies may also detect chemical signals or vibrations from neighboring colonies beginning their flights

3. Colony Maturity and Seasonal Timing

Colony Age:

- Only mature colonies (typically 3-6 years old for carpenter ants) produce alates
- Young colonies invest all resources into growth, not reproduction
- Mature colonies can afford the enormous energy investment of producing winged reproductives

Seasonal Preparation:

- Colonies begin developing alates weeks or months before the flight
- These special larvae receive extra nutrition and develop into winged forms
- They wait inside the nest until conditions are perfect
- In many regions, this happens during specific seasons (spring or monsoon seasons)

First Significant Rain:

- Often, it's the first substantial rainfall after a dry period that triggers the mass flight
- This timing ensures maximum soil moisture and minimal competition
- In tropical regions, the first monsoon rains trigger spectacular emergences

4. The Role of Worker Ants

Worker ants play a crucial supporting role in the emergence:

Exit Preparation:

- Workers excavate and clear exit passages days before the flight
- They remove debris and enlarge openings
- Multiple exits are prepared to allow rapid mass exodus

Traffic Control:

- Workers guide alates toward exits
- They may physically push or pull reluctant alates
- Workers prevent premature exits when conditions aren't optimal

Protection:

- Workers defend the exits from predators during emergence
- They form protective corridors for the departing alates
- After the flight, workers seal the entrances again

5. Increased Surface Activity

Beyond the winged reproductives, you also see increased activity of regular worker ants after rain:

Foraging Opportunities:

- Rain brings earthworms and other prey to the surface
- Soil-dwelling insects become more accessible
- Seeds and food particles are exposed by water runoff
- Wet conditions make it easier to detect food chemically

Nest Maintenance:

- Workers must repair water damage to the nest
- They relocate brood (eggs, larvae, pupae) if areas become flooded
- Drainage channels need to be cleared or excavated

Reduced Desiccation Risk:

- Normal foraging is risky in dry conditions for ants
- Post-rain humidity allows safer extended foraging trips
- Workers can travel further from the nest without dehydration risk

Territory Expansion:

- Some colonies use post-rain conditions to expand their territory
- Scout ants explore new areas when conditions are favorable
- Competing colonies may engage in territorial disputes

The Nuptial Flight Process

Understanding what happens during and after emergence helps explain why you see so many ants:

Stage 1: Pre-Flight Assembly

- Alates gather near nest exits hours before flight
- Colony becomes highly agitated and active
- Workers make final preparations

Stage 2: Mass Exodus

- When conditions are optimal (usually late afternoon/early evening after rain)
- Hundreds or thousands of winged ants pour from the nest within minutes
- They climb vegetation, walls, or any vertical surface to gain height

Stage 3: Flight and Mating

- Alates take to the air in what appears as a swarm
- Mating typically occurs in flight or immediately after landing
- Males die shortly after mating (within hours or days)
- Mated queens land and immediately search for nesting sites

Stage 4: Queen Establishment

- Queens shed their wings by breaking them off at predetermined fracture points
- The shed wings are often the first sign people notice after a swarm
- Queens dig into softened soil to create their founding chamber
- They seal themselves in and begin laying eggs

Stage 5: Colony Foundation

- The queen survives on stored fat reserves and her now-useless flight muscles (which she metabolizes)
- She cares for her first brood alone without leaving the chamber
- First workers emerge in 6-12 weeks and take over all tasks
- The new colony slowly grows over years

Chemical and Physiological Factors

Pheromone Communication:

- Queens release "calling pheromones" before and during emergence
- These chemical signals coordinate the timing of the flight within the colony

- Alarm pheromones may also play a role if the colony senses danger

Hormonal Regulation:

- Juvenile hormone levels in alates peak before flights
- Environmental cues (rain, humidity, temperature) trigger hormonal changes
- These hormones drive the behavioral changes that lead to emergence

Circadian Rhythms:

- Most ant nuptial flights occur at specific times of day
- Many species prefer late afternoon or early evening
- This timing reduces exposure to extreme heat and diurnal predators

Regional and Species Variations

Different species and geographic regions show variations:

Tropical Regions:

- Flights often coincide with monsoon onset
- Multiple species may fly on the same evening
- Year-round warmth allows multiple flight periods

Temperate Regions:

- Flights typically occur in late spring or summer
- Species show distinct seasonal preferences
- Carpenter ants often fly in late spring/early summer

Desert Regions:

- Rare but heavy rains trigger dramatic synchronized flights
- Ants may wait years for suitable conditions
- Emergence events are particularly spectacular due to their rarity

Why This Behavior Evolved

The rain-triggered nuptial flight represents millions of years of evolutionary refinement:

Survival Optimization:

- Maximizes queen survival during the most vulnerable phase
- Ensures new colonies are founded under optimal conditions
- Reduces competition by temporal spacing of flights

Dispersal Efficiency:

- Wind and weather patterns after rain aid dispersal
- Reduces colony density and competition with parent colony
- Promotes genetic mixing across populations

Resource Availability:

- Post-rain conditions improve food availability
- Softened soil contains more accessible prey
- Plant growth accelerates, supporting herbivorous prey

What To Expect After the Emergence

Short-term (Hours to Days):

- Shed wings scattered on the ground, sidewalks, near lights
- Dead or dying male ants (their life's purpose fulfilled)
- Increased bird and other predator activity
- Queens frantically searching for nesting sites

Medium-term (Weeks):

- Most queens will have died (90-95% mortality rate)
- Successful queens are sealed in underground chambers
- Surface activity returns to normal
- No visible signs of the recent emergence

Long-term (Months to Years):

- Surviving queens produce their first workers
- New colonies very slowly establish
- In 3-6 years, these colonies may produce their own alates
- The cycle continues

Common Concerns and Facts

Are they dangerous?

- Carpenter ants can bite but rarely do unless handled
- They don't sting (unlike fire ants or some other species)
- The emergence itself poses no threat to humans

Will they infest my home?

- Winged ants are looking for nesting sites, not food
- Mated queens seek soil, not structures (usually)
- Carpenter ants do nest in wood but prefer dead, moist wood outdoors
- Seal entry points if concerned, but most queens die quickly

Should I kill them?

- The emergence is a natural ecological event
- Ants play crucial roles in ecosystems (aeration, seed dispersal, pest control)
- Most queens will die naturally regardless of intervention
- If concerned about indoor invasion, simply prevent entry rather than mass killing

Conclusion

The emergence of big black ants after rain is a spectacular natural phenomenon driven by the need for optimal conditions during the most critical phase of the ant life cycle - colony founding. Rain provides the perfect combination of high humidity (preventing desiccation), soft soil (enabling nest excavation), moderate temperatures, and predator satiation through synchronized mass emergence. This behavior represents a finely tuned evolutionary strategy that has ensured ant success for over 100 million years. The next time you see these winged giants emerging after a storm, you're witnessing one of nature's most ancient and successful reproductive strategies in action - a brief but crucial moment when new colonies are born and genetic diversity is shuffled across the landscape.

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Eat Variety of Foods to Ensure a Balanced Diet

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Introduction

Nutrition is the foundation of health and well-being, providing the essential nutrients required for growth, development, and the maintenance of body functions. A balanced diet, which includes a variety of foods from different food groups, ensures that the body receives adequate amounts of carbohydrates, proteins, fats, vitamins, minerals, and other bioactive compounds necessary for optimal physiological and biochemical functioning (Gropper & Smith, 2022).

Variety in the diet is not only crucial for meeting energy and nutrient needs but also for promoting long-term health and preventing both undernutrition and overnutrition. Diets limited to a few food items can lead to deficiencies of essential nutrients, impaired immunity, reduced cognitive and physical performance, and increased susceptibility to chronic diseases (FAO/WHO, 2021). Conversely, a diverse diet that combines cereals, millets, pulses, vegetables, fruits, milk, and sources of healthy fats provides comprehensive nutrition, supports growth and development, and reduces the risk of diet-related disorders such as obesity, diabetes, cardiovascular diseases, and micronutrient deficiencies (WHO, 2020).

In India, where dietary patterns vary widely across regions, socioeconomic groups, and age categories, emphasizing dietary diversity is particularly important. Incorporating a wide range of foods ensures that all population groups from infants and children to pregnant women, lactating mothers, and adults receive adequate nutrition for maintaining health, supporting physical activity, and improving quality of life. Thus, eating a variety of foods is the cornerstone of a balanced diet and overall well-being.

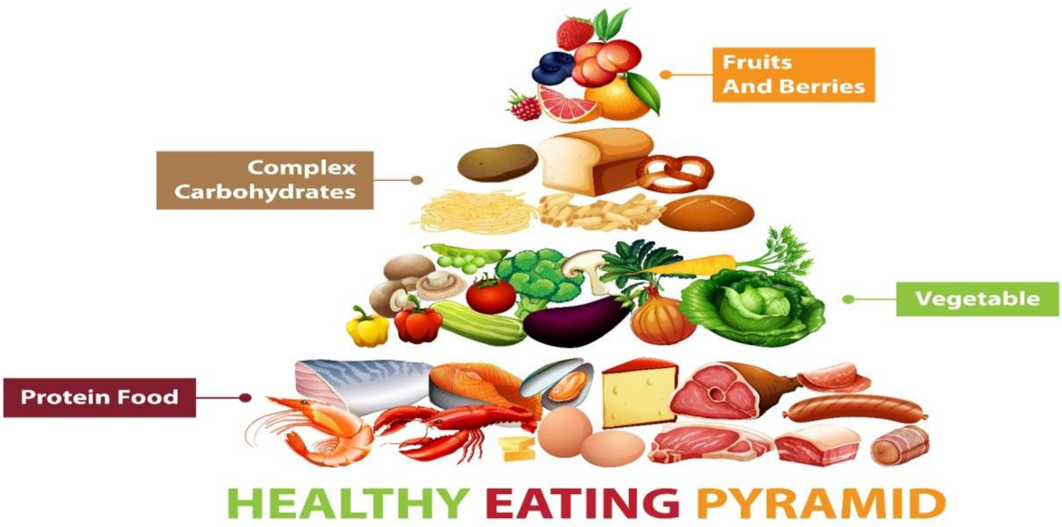
Nutritionally adequate diet should be consumed through a wise choice from a variety of foods

- **Nutrition is essential for life:** Nutrition forms the foundation for sustaining life, supporting physical growth, maintaining normal physiological functions, and preventing diseases. Adequate intake of nutrients is critical for overall health and well-being (Gopalan et al., 2021). Variety in food not only enhances taste but ensures comprehensive nutrient intake.
- **Balanced intake from multiple food groups:** A diet comprising foods from diverse food groups provides all essential macronutrients (carbohydrates, proteins, fats) and micronutrients (vitamins and minerals) in proper amounts. This helps prevent deficiency disorders and supports optimal growth, development, and immunity (FAO/WHO, 2020).
- **Cereals, millets, and pulses as nutrient sources:** Cereals and millets are primary sources of energy (carbohydrates) and provide dietary fiber, B-complex vitamins, and some minerals. Pulses are rich in plant-based proteins, iron, and zinc. Together, these form the backbone of nutritionally adequate diets, especially in developing countries (National Institute of Nutrition, 2023).
- **Milk and dairy products:** Milk and its derivatives supply high-quality proteins, calcium, phosphorus, and fat-soluble vitamins (A, D). They are particularly important for infants, growing children, and women to support bone development, growth, and reproductive health (RDA, 2020).

- **Oils, nuts, and calorie-dense foods:** Oils and nuts are rich in energy, essential fatty acids, and fat-soluble vitamins, improving the energy density and nutritional quality of meals. Inclusion of eggs, fish, and lean meats enhances protein quality and provides vital micronutrients like vitamin B^{12}, iron, and omega-3 fatty acids (Gopalan et al., 2021).
- **Vegetables and fruits as protective foods:** Vegetables and fruits supply vitamins (A, C, K), minerals (potassium, magnesium), fiber, and phytonutrients such as polyphenols and carotenoids. These compounds protect against oxidative stress, reduce the risk of chronic diseases, and support immune function (Boeing et al., 2012).
- **Vegetarian diets:** Vegetarians can meet almost all nutritional needs by combining cereals, pulses, vegetables, fruits, and dairy. Proper combinations of plant-based foods ensure intake of all essential amino acids, vitamins, and minerals, making vegetarian diets nutritionally adequate when well-planned (National Institute of Nutrition, 2023).
- **Importance of dietary diversity:** Diversified diets that include foods from multiple groups ensure adequate intake of energy, proteins, vitamins, minerals, and protective phytochemicals. This strategy reduces the risk of both undernutrition and diet-related chronic diseases, supporting lifelong health (FAO/WHO, 2020).

Why do we need nutritionally adequate food?

Nutrients obtained from food play a crucial role in human growth, development, and overall health. They support physical growth during childhood and adolescence, maintain normal physiological functions, enable physical activity, and strengthen immunity. Consuming a nutritionally adequate diet is essential for sustaining life and activity across all stages of life (Gopalan et al., 2021). The requirements for essential nutrients vary depending on age, gender, physiological status, and level of physical activity. Insufficient intake of nutrients can lead to undernutrition, causing deficiency diseases, impaired growth, and reduced work capacity, whereas excessive intake can result in overnutrition, contributing to obesity, cardiovascular diseases, diabetes, and other non-communicable disorders (FAO/WHO, 2020). Critical periods such as infancy, childhood, adolescence, pregnancy, and lactation are especially sensitive to nutrient deficiencies, and even shortfalls during these stages can have long-term consequences. Conversely, overconsumption at any stage of life may increase the risk of chronic diseases. Therefore, an adequate and balanced diet providing all essential nutrients in proper amounts is needed throughout life. Achieving this requires a judicious selection and combination of foods from different groups, including cereals, pulses, vegetables, fruits, dairy, oils, nuts, and, for non-vegetarians, eggs, meat, and fish, ensuring nutritional adequacy, variety, and optimal health (National Institute of Nutrition, 2023).



Carbohydrates: The Primary Energy Source

1. **Classification of carbohydrates:** Carbohydrates are broadly classified as simple or complex. Simple carbohydrates include monosaccharides like glucose and fructose, present in fruits, vegetables, and

honey, and disaccharides such as sucrose in sugar and lactose in milk. Complex carbohydrates include starches in cereals, millets, pulses, and root vegetables, and glycogen stored in animal tissues (Gopalan et al., 2021).

2. **Energy contribution:** Carbohydrates provide 4 kcal per gram, making them the main source of dietary energy. They fuel basal metabolism, physical activity, and growth, and are especially important in energy-dense diets for populations with high activity levels (FAO/WHO, 2020).
3. **Dietary fiber:** Certain complex carbohydrates, including cellulose, gums, and pectins, are resistant to digestion and form dietary fiber. Fiber helps regulate bowel movements, delays glucose absorption, reduces cholesterol levels, and increases satiety, contributing to overall metabolic health (Slavin, 2013).
4. **Role in Indian diets:** In India, 70-80% of total dietary calories are derived from carbohydrates, primarily from plant sources like cereals, millets, and pulses. This makes carbohydrates the cornerstone of energy supply in typical Indian diets, particularly in rural and low-income households (National Institute of Nutrition, 2023).
5. **Health considerations:** Diets rich in complex carbohydrates and fiber are associated with reduced risk of type 2 diabetes, obesity, and cardiovascular diseases, whereas excessive intake of refined sugars can lead to energy imbalance and metabolic disorders (WHO, 2022).

Proteins: The Building Blocks of Life

1. **Definition and Structure:** Proteins are primary structural and functional components of every living cell. Approximately 50% of the body's protein is found in muscles, while the rest is distributed in bones, cartilage, skin, blood, and organs (Gropper & Smith, 2022). Proteins are composed of amino acids, which form complex three-dimensional structures necessary for their biological functions.
2. **Essential vs Non-Essential Amino Acids: Essential amino acids** cannot be synthesized by the human body and must be obtained from the diet. **Non-essential amino acids** can be synthesized by the body from other nutrients. A balanced intake ensures that all amino acids required for growth, repair, and metabolic functions are available (FAO/WHO, 2020).
3. **Functions of Proteins:** Proteins perform structural, enzymatic, hormonal, and immune functions, in addition to providing energy at 4 Kcal/g. Key functions include: Muscle development and repair, Enzyme and hormone synthesis, Immune system support, Transport of nutrients and oxygen in blood (National Institute of Nutrition, 2023)
4. **Dietary Requirements:** Protein needs vary with age, physiological status, and stress: Infants and children require more proteins for growth. Pregnant and lactating women need additional protein for fetal development and milk production. Individuals under stress or illness require increased protein for tissue repair and immune support (WHO, 2022).
5. **Sources of Proteins: Animal sources**: Milk, eggs, fish, meat considered high-quality proteins as they provide all essential amino acids in optimal proportions. Plant sources: Pulses, legumes, cereals, and millets generally incomplete proteins, but complementary combinations (e.g., rice with dal) provide all essential amino acids (Gopalan et al., 2021).
6. **Health Implications:** Adequate protein intake supports healthy growth, muscle maintenance, wound healing, and metabolic health. Deficiency can lead to stunted growth, muscle wasting, and impaired immunity, whereas excessive protein intake without balance may stress kidneys or liver (Slavin & Lloyd, 2012).

Fats: Concentrated Energy and Essential Nutrients

1. **Definition and Sources:** Fats are a concentrated source of energy providing 9 Kcal per gram. They are composed of fatty acids and are classified as: **Visible fats:** Added oils and fats such as butter, ghee, vanaspati, and cooking oils. **Invisible fats:** Naturally present in plant and animal foods like nuts, seeds, dairy, and meat (Gropper & Smith, 2022).
2. **Physiological Functions:** Fats play multiple vital roles in the body: Energy provision: Fats provide more than double the energy of carbohydrates or proteins. Absorption of fat-soluble vitamins: Vitamins A, D, E, and K, and carotenoids require fat for absorption (FAO, 2020). Source of essential fatty acids:

Polyunsaturated fatty acids (PUFAs) like omega-3 and omega-6 are necessary for cell membrane integrity, brain development, and cardiovascular health (Simopoulos, 2016).

3. **Dietary Requirements:** Infants and children require higher energy per kg body weight for growth and development; hence, dietary fats are essential in their diet. Adults should focus on moderation and quality of fat intake, prioritizing unsaturated fats from plant oils, nuts, seeds, fish, and avoiding excessive saturated and trans fats (WHO, 2022).
4. **Impact on Health:** Excess intake of saturated fats and cholesterol (butter, ghee, hydrogenated fats, red meat, organ meat, eggs) is linked to obesity, type 2 diabetes, cardiovascular disease, and certain cancers (Mozaffarian et al., 2010). Balanced fat intake contributes to satiety, hormonal balance, brain function, and overall metabolic health.
5. **Recommendations:** Daily intake: Fat should constitute 20-30% of total daily calories, with a focus on polyunsaturated and monounsaturated fatty acids. Cooking practices: Prefer minimal use of hydrogenated fats, and include sources of omega-3 fatty acids such as flaxseed, walnuts, and fatty fish.

Vitamins and Minerals: Micronutrients Essential for Health

1. **Definition and Importance:** Vitamins are organic compounds required in small amounts that the body cannot synthesize in sufficient quantities. They are essential for growth, development, immune function, and maintenance of skin, bones, nerves, eyes, brain, blood, and mucous membranes (Gropper & Smith, 2022). Minerals are inorganic elements found in body fluids and tissues that regulate cell function, enzyme activity, and physiological processes (FAO, 2020).
2. **Classification of Vitamins:** Fat-soluble vitamins: A, D, E, K stored in the liver and adipose tissues; essential for vision, bone health, antioxidant function, and blood coagulation (Ross et al., 2020). Water-soluble vitamins: C and B-complex (thiamin B1, riboflavin B2, niacin B3, pyridoxine B6, folic acid, cyanocobalamin B^{12}) not stored in the body; excess is excreted via urine. These vitamins are heat-labile, meaning they can be destroyed during cooking or processing (Wardlaw & Hampl, 2021). Pro-vitamin: Beta-carotene, which is converted to vitamin A in the body, supports vision, immunity, and antioxidant defenses.
3. **Functions of Vitamins: Vitamin A:** Vision, skin integrity, immune system. Vitamin D: Calcium absorption, bone mineralization. Vitamin E: Antioxidant protection, cellular membranes. Vitamin K: Blood clotting and bone metabolism. Vitamin C & B-complex: Energy metabolism, red blood cell formation, nerve function, and tissue repair.
4. **Classification of Minerals:** Macrominerals: Sodium (Na), Potassium (K), Calcium (Ca), Phosphorus (P), Magnesium (Mg), Sulfur (S) required in larger amounts for electrolyte balance, bone health, muscle function, and enzyme activation (Gropper & Smith, 2022). Trace minerals (microminerals): Zinc (Zn),

Copper (Cu), Selenium (Se), Molybdenum (Mo), Fluorine (F), Cobalt (Co), Chromium (Cr), Iodine (I) required in small quantities but are critical for enzyme activity, hormone synthesis, and antioxidant protection (WHO, 2021).

5. **Physiological Significance:** Minerals and vitamins collectively maintain: Structural integrity: Skin, hair, nails, bones, teeth. Metabolic functions: Enzyme activity, hormone production, nerve impulse transmission. Homeostasis: Acid-base balance, fluid balance, blood clotting.
6. **Dietary Sources: Vitamins:** Fruits, vegetables, dairy, eggs, liver, fortified foods. **Minerals:** Milk, cereals, pulses, nuts, seeds, seafood, and green leafy vegetables.
7. **Key Recommendations:** Consume a variety of fruits, vegetables, whole grains, dairy, and fortified foods to ensure adequate intake of both vitamins and minerals. Be mindful that overcooking or processing can destroy heat-sensitive vitamins (Wardlaw & Hampl, 2021). Inclusion of both macro and micro minerals in the diet is critical for optimal growth and prevention of deficiency diseases like anemia, rickets, goiter, and osteoporosis.

Balanced Diet: Definition and Importance

A balanced diet is one that provides all essential nutrients in the required amounts and proper proportions to maintain growth, health, and physiological function. It ensures that the body receives sufficient energy, macronutrients, micronutrients, and protective compounds necessary for optimal physical and mental performance (Gropper & Smith, 2022).

1. **Macronutrient Composition:**
   - **Carbohydrates:** 50-60% of total daily calories, preferably from complex carbohydrates such as whole grains, cereals, millets, pulses, and vegetables. Complex carbs provide sustained energy and are rich in dietary fiber, which helps regulate digestion and blood glucose (FAO, 2020).
   - **Proteins:** 10-15% of total calories, from high-quality sources like milk, eggs, fish, meat, pulses, legumes, and nuts. Proteins are essential for tissue repair, growth, enzyme function, and immune response (Ross et al., 2020).
   - **Fats:** 20-30% of total calories, from both visible (oils, butter, ghee) and invisible fats (present in plant and animal foods). Fats are a concentrated energy source, facilitate absorption of fat-soluble vitamins (A, D, E, K), and provide essential fatty acids (Wardlaw & Hampl, 2021).
2. **Micronutrients and Protective Compounds:** A balanced diet also includes vitamins, minerals, dietary fiber, antioxidants, and phytochemicals, which offer protective health benefits:

- **Antioxidants:** Vitamins C and E, beta-carotene, riboflavin, and selenium neutralize free radicals, reducing oxidative stress (Halliwell & Gutteridge, 2015).
- **Phytochemicals:** Polyphenols, flavonoids, and carotenoids from fruits, vegetables, spices, and herbs (like turmeric, ginger, garlic, cumin, cloves) provide additional protection against chronic diseases (Liu, 2013).

3. **Dietary Variation:** Achieving a balanced diet requires variety across food groups, including cereals, millets, pulses, vegetables, fruits, dairy, eggs, meat, fish, and healthy fats. Quantities and combinations depend on age, gender, physiological status, and physical activity level. Active individuals need higher energy intake, while sedentary adults require moderate energy intake.
4. **Practical Implementation:** Sample menus for sedentary, moderate, and heavy activity adults show how to meet nutrient requirements while incorporating local and seasonal foods. Emphasis is placed on portion control, combination of food groups, and inclusion of nutrient-dense foods to prevent undernutrition or overnutrition.
5. **Overall Significance:** A well-planned balanced diet enhances immunity, supports growth, maintains body weight, prevents nutrient deficiencies, and reduces the risk of non-communicable diseases such as diabetes, cardiovascular disease, and obesity (WHO, 2021).

Table 1: Classification of foods based on function

Major Nutrients		**Other Nutrients**
Energy Rich Foods	**Carbohydrates & fats**	
	Whole grain cereals, millets	Protein, fibre, minerals, calcium, iron & B-complex vitamins
	Vegetable oils, ghee, butter	Fat soluble vitamins, essential fatty acids
	Nuts and oilseeds	Proteins, vitamins, minerals
	Sugars	Nil
Body Building Foods	**Proteins**	
	Pulses, nuts and oilseeds	B-complex vitamins, invisible fat, fibre
	Milk and Milk products	Calcium, vitamin A, riboflavin, vitamin B12
	Meat, fish, poultry	B-complex vitamins, iron, iodine, fat
Protective Foods	**Vitamins and Minerals**	
	Green leafy vegetables	Antioxidants, fibre and other carotenoids
	Other vegetables and fruits	Fibre, sugar and antioxidants
	Eggs, milk and milk products and flesh foods	Protein and fat

Nutrient Requirements and Recommended Dietary Allowances (RDA)

Nutrient requirements refer to the quantities of essential nutrients that healthy individuals must obtain from their diet to meet physiological needs and maintain optimal growth, development, and health (Gropper & Smith, 2022). These nutrients include macronutrients carbohydrates, proteins, and fats and micronutrients such as vitamins and minerals.

Recommended Dietary Allowances (RDA) are estimates of the daily intake of nutrients sufficient to meet the needs of nearly all (97-98%) healthy individuals in a specific population group. The RDA is not a fixed requirement; it considers the bioavailability of nutrients, which refers to the proportion of nutrients that is absorbed and utilized by the body (Institute of Medicine, 2006). To account for individual variation, dietary traditions, and differences in absorption, RDA includes a margin of safety.

RDAs are established for different physiological and life-stage groups, such as infants, preschooler's, children, adolescents, adults, pregnant women, and lactating mothers. They also take into account physical activity levels, since nutrient and energy needs vary between sedentary, moderately active, and highly active individuals. While daily intakes may fluctuate depending on food availability and individual energy demands, the average intake over time should meet or exceed the RDA to prevent nutrient deficiencies (FAO/WHO, 2021).

In some situations, diet alone may not provide adequate nutrients, especially for vulnerable groups or populations at risk of deficiencies. In such cases, fortified foods can help meet nutritional needs. A classic example is iodized salt fortified with iron, which addresses both iodine and iron deficiencies prevalent in many regions (WHO, 2021).

Meeting the RDA ensures adequate calories, proteins, and micronutrients are available to achieve maximum growth potential, optimal health, and prevention of deficiency diseases. Proper nutrition during key life stages infancy, childhood, adolescence, pregnancy, and lactation is critical for long-term health outcomes.

Guidelines for Healthy Eating

- Healthy eating involves consuming a variety of foods in suitable amounts according to age, gender, and activity level to meet all nutritional needs.
- A balanced mix of whole grains, pulses, millets, and leafy vegetables provides essential carbohydrates, proteins, vitamins, and minerals.
- Moderate use of jaggery, sugar, and cooking oils helps maintain proper energy balance.
- Fresh and locally available fruits and vegetables supply vital antioxidants and phytonutrients that protect the body from oxidative stress. Including milk, eggs, and lean meat supports growth, maternal health, and nutrient adequacy, especially in children and women.
- Adults should opt for low-fat, protein-rich foods like fish, pulses, and low-fat dairy to promote metabolic health and prevent chronic diseases.
- Adopting healthy eating habits along with regular physical activity ensures overall well-being and reduces the risk of lifestyle-related disorders.

Conclusion

A balanced and varied diet is the foundation of good health and overall well-being. Consuming a wide range of foods from all food groups in appropriate proportions provides the body with essential nutrients required for growth, energy, immunity, and disease prevention. Each food group contributes uniquely cereals and millets supply energy, pulses provide proteins, fruits and vegetables offer vitamins and minerals, while milk, eggs, and other animal foods enhance the quality of protein and micronutrient intake.

Incorporating dietary diversity not only meets physiological needs but also helps prevent nutritional deficiencies and lifestyle-related diseases such as obesity, diabetes, and cardiovascular disorders. It is equally important to select fresh, locally available, and seasonal foods, adopt healthy cooking methods, and maintain regular physical activity for optimum health.

Ultimately, ensuring a varied diet is not just a matter of choice but a vital step toward achieving nutritional security, maintaining vitality, and enhancing the quality of life for individuals across all age groups. Thus, "Eating a variety of foods every day is the simplest way to stay healthy, active, and disease-free."

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Avoid Overeating to Prevent Overweight and Obesity

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Introduction

Overeating, defined as the consumption of calories exceeding physiological energy requirements, is a major contributor to overweight and obesity, conditions recognized as global public health challenges. Obesity prevalence has increased sharply worldwide; in 2022, approximately 2.5 billion adults were classified as overweight, including 890 million with obesity (WHO, 2024). In India, recent data from the National Family Health Survey-5 (NFHS-5, 2019-21) indicate that 24 % of women and 23 % of men aged 15-49 are overweight or obese, reflecting a significant rise over the past decade International Institute for Population Sciences (IIPS), 2022.

The primary pathophysiological mechanism underlying weight gain is a sustained positive energy balance, resulting from excessive caloric intake relative to energy expenditure (Gupta et al., 2023). Contributing factors include high consumption of energy-dense and processed foods, increased portion sizes, frequent snacking, and sedentary lifestyles (Popkin et al., 2023). Overeating not only promotes adiposity but also increases the risk of metabolic disorders such as type 2 diabetes, hypertension, cardiovascular disease, and certain cancers (Hruby & Hu, 2015).

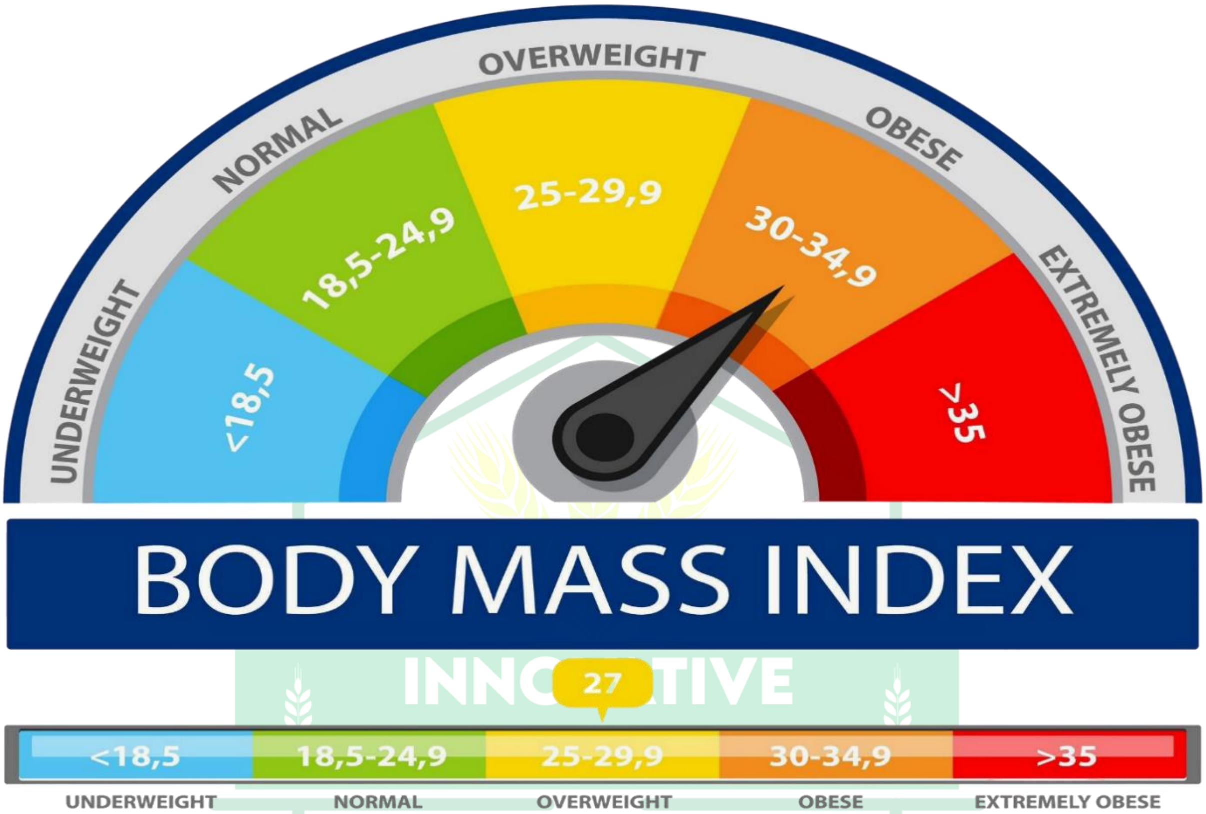
Evidence-based interventions suggest that moderating caloric intake through portion control, consumption of nutrient-dense foods, and alignment of energy intake with physical activity effectively prevent excessive weight gain and reduce obesity-related morbidity (World Obesity Federation, 2024). Addressing overeating at both individual and population levels is therefore critical for mitigating the rising burden of obesity and associated non-communicable diseases, particularly in countries undergoing rapid nutrition transitions, such as India.

Overweight and obesity are major risk factors for numerous chronic non-communicable diseases, including cardiovascular diseases, type 2 diabetes, and certain types of cancers (Hruby & Hu, 2015). Over the last 2-3 decades, the prevalence of overweight and obesity has increased dramatically across all age groups worldwide and in India. Recent estimates suggest that approximately 30-50% of adult Indians are either overweight or obese (IIPS, 2022). Individuals with excess body weight are at heightened risk of comorbidities such as fatty liver disease, gallstones, dyslipidemia, hypertension, osteoarthritis, and psychosocial problems (Gupta et al., 2023). The primary underlying cause is a sustained imbalance between energy intake and energy expenditure, leading to excessive accumulation of adipose tissue in various regions of the body. Addressing overeating and promoting energy balance are therefore critical strategies to prevent overweight, obesity, and associated health complications (World Obesity Federation, 2024).

Desirable or Ideal Body Weight and Body Mass Index (BMI): There is no universally fixed definition of a desirable or ideal body weight. Generally, ideal body weight refers to the weight at which a person maintains good health and has a higher likelihood of longevity. A practical and widely used measure to assess body weight relative to height is the Body Mass Index (BMI), which correlates strongly with body fat percentage.

BMI is calculated using the formula:

$$BMI = \frac{\text{Weight (kg)}}{\text{Height (m)}^2}$$



Based on BMI, individuals can be categorized into underweight, normal (ideal), overweight, or obese, according to the cut-off points recommended by the World Health Organization (WHO, 2021). These classifications help identify people at risk of weight-related health complications and are useful for public health monitoring and guidance.

Obesity:

Obesity is a condition characterized by excessive accumulation of body fat that poses a risk to health. Beyond total fat accumulation, the distribution of fat, particularly around the abdomen, is considered more harmful than peripheral fat deposition, as indicated by higher waist circumference, which is a significant risk factor for metabolic and cardiovascular diseases (WHO, 2021).

Body Mass Index (BMI) is widely used to define overweight and obesity. For adults, a BMI of 18.5-25 kg/m² is considered normal. However, for Asian populations, a lower BMI range of 18.5-23 kg/m² is recommended due to higher body fat percentage at lower BMI levels, increasing susceptibility to chronic non-communicable diseases (NCDs) such as diabetes, hypertension, and cardiovascular disorders (WHO, 2004; Misra & Khurana, 2008).

For children and adolescents, obesity classification uses age- and sex-specific BMI percentiles, reflecting differences in growth patterns. Children below the 5^{th} percentile are considered undernourished, those between the 5^{th} and 85^{th} percentiles are normal, the 85^{th} to <95th percentiles indicate overweight, and above the 95th percentile are classified as obese (Cole et al., 2000). These criteria help identify at-risk populations early and guide preventive strategies.

Central Obesity:

Central obesity refers to the excessive accumulation of fat in the abdominal region and is a key predictor of metabolic and cardiovascular risk. Waist circumference (WC) and waist-to-hip ratio (WHR) are commonly used anthropometric measures to assess central and truncal obesity, respectively (WHO, 2008). N umerous studies have demonstrated a strong association between central obesity and chronic degenerative diseases, particularly metabolic syndrome, type 2 diabetes, and cardiovascular disorders (Després, 2012).

In Asian Indian populations, central obesity is considered present when WC exceeds 90 cm in men and 80 cm in women, or when WHR is greater than 0.9 in men and 0.8 in women. These cut-off values are associated with a significantly higher risk of hypertension, dyslipidemia, insulin resistance, and other obesity-related complications (Misra & Vikram, 2004; WHO, 2008). The disproportionate accumulation of visceral fat, rather than overall body weight, is now recognized as a stronger predictor of morbidity and mortality from chronic diseases.

Why Should We Avoid Obesity?

Obesity is associated with multiple adverse health outcomes and is a major risk factor for chronic non-communicable diseases. Excess body fat increases the likelihood of cardiovascular diseases, including coronary artery disease and hypertension, as well as type 2 diabetes, gallstones, osteoarthritis, and certain cancers (Hruby & Hu, 2015). Obesity negatively affects lipid metabolism, leading to reduced levels of high-density lipoprotein (HDL, "good" cholesterol), elevated low-density lipoprotein (LDL, "bad" cholesterol), and increased triglycerides. It also contributes to insulin resistance and hyperglycemia, further exacerbating the risk of metabolic disorders (Ng et al., 2014).

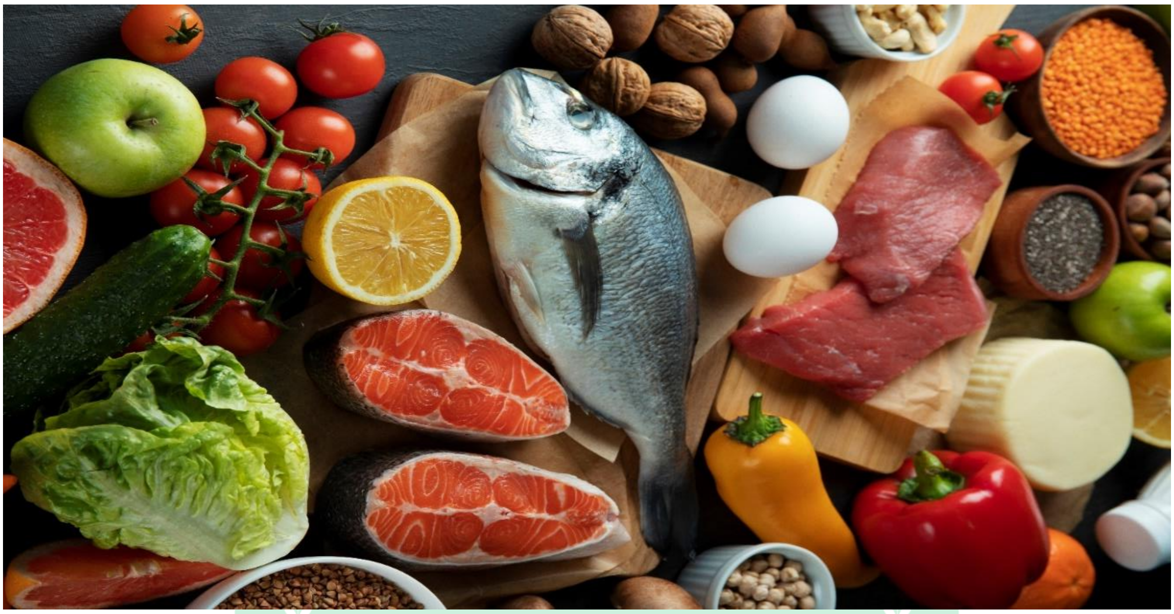
In India, the prevalence of obesity and associated cardiometabolic disorders has been rising dramatically over the past few decades, affecting both urban and rural populations (Anjana et al., 2017). Maintaining a desirable body weight relative to height, measured using body mass index (BMI) and waist circumference, is therefore critical to reducing the risk of these health complications and promoting overall long-term health.

What Causes Obesity?

Obesity results from a complex interplay of genetic, behavioral, environmental, and metabolic factors that lead to chronic positive energy balance. Overfeeding during infancy, childhood, and adolescence significantly increases the risk of overweight and obesity in adulthood (Singh et al., 2021). Genetic predisposition also plays a role, as familial obesity patterns indicate heritable tendencies toward higher body fat (Loos & Yeo, 2022).

Dietary patterns, particularly the frequent consumption of energy-dense, nutrient-poor "junk" foods combined with low physical activity, are major contributors to the rising prevalence of obesity (Popkin & Ng, 2022). Behavioral and psychological factors, including emotional eating and disrupted satiety signaling, further influence food intake and weight gain. Metabolic and hormonal factors, particularly insulin, modulate energy storage and fat deposition, contributing to excess adiposity (Samuel & Shulman, 2012).

Epidemiological studies indicate that both low (<2500 g) and high (>3500 g) birth weights are associated with increased risk of obesity later in life, and childhood obesity strongly predicts adult obesity (Biro & Wien, 2010). Sedentary behaviors, such as prolonged television viewing, are linked to increased weight gain among children and adolescents due to reduced physical activity and increased consumption of energy-dense snacks (Andersen et al., 2019). In adults, weight gain is commonly observed between ages 25-50, with women being particularly susceptible to obesity during post-pregnancy and post-menopausal periods (World Health Organization, 2021). Maintaining energy balance through controlled caloric intake and regular physical activity is essential for preventing obesity across the lifespan.



How to Reduce Body Weight

Weight reduction should be gradual, individualized, and aimed at sustainable long-term outcomes. Safe weight loss is generally 0.5-1 kg per week, and very low-calorie diets (<1000 kcal/day) should be avoided as they may lead to nutrient deficiencies and metabolic disturbances (Hill et al., 2012). Extreme dieting and unsupervised use of weight-loss drugs can be dangerous and are not recommended.

For children, obesity management focuses on increasing physical activity rather than severe caloric restriction, as growth and development must be supported (Baur et al., 2018). Reducing dietary fat is important because fat contains 9 kcal/g, more than twice that of carbohydrates or proteins (4 kcal/g each), and limiting refined sugars, alcohol, and high-glycemic-index carbohydrates can prevent excess caloric intake and spikes in blood glucose (Ludwig, 2020).

Weight-loss diets should prioritize plant-based foods, complex carbohydrates, dietary fiber, lean proteins, and low-fat dairy, which promote satiety, stabilize blood glucose, and support micronutrient intake (Johnston et al., 2021). Adequate fruits and vegetables help maintain satiety while supplying essential vitamins and minerals. Cyclic fasting or repeated extreme caloric restriction should be avoided, as these can lead to rebound weight gain and metabolic disturbances (Trepanowski & Bloomer, 2010). All weight-loss regimens should ideally be supervised by healthcare professionals, including dietitians and physicians, to ensure safety and effectiveness.

Healthy Weight Management

1. Weight reduction should be gradual and steady to ensure sustainability and avoid adverse health effects (Hill et al., 2012).
2. Severe fasting or extreme caloric restriction can be hazardous and may lead to nutrient deficiencies, metabolic disturbances, and rebound weight gain (Trepanowski & Bloomer, 2010).
3. Maintaining energy balance matching caloric intake with expenditure—is essential to achieve and sustain appropriate weight for height (WHO, 2020).

4. Regular physical activity should be encouraged, as it helps in weight control, improves cardiovascular health, and enhances metabolic function (Biddle et al., 2019).
5. Eating small, frequent meals can prevent overeating, stabilize blood glucose, and improve satiety (Johnston et al., 2021).
6. Reduce intake of sugar, salt, refined foods, soft drinks, and alcohol, as these contribute to excess calorie intake and metabolic disorders (Malik et al., 2010).
7. Prefer complex carbohydrates, low glycemic index foods, and fiber-rich diets to enhance satiety, control blood glucose, and support gut health (Slavin, 2013).
8. Increase consumption of fruits, vegetables, legumes, whole grains, and nuts to provide essential vitamins, minerals, antioxidants, and dietary fiber (Boeing et al., 2012).
9. Limit total fat intake and replace saturated fats with unsaturated fats from plant oils, nuts, seeds, and fatty fish to reduce cardiovascular risk (Mozaffarian et al., 2010).
10. Avoid trans-fatty acids found in vanaspati, bakery products, and commercial fried foods, as they increase the risk of coronary heart disease (Mozaffarian et al., 2006).
11. Use low-fat or skimmed milk and dairy products to reduce calorie intake while maintaining protein and calcium needs (Gopalan et al., 2021).
12. Monitor weight regularly and seek guidance from a dietitian or physician to develop individualized weight management plans (WHO, 2021).
13. Incorporate behavioral strategies such as mindful eating and reducing sedentary behaviors (screen time) to prevent overeating (Robinson et al., 2017).

Conclusion

Overeating is a key contributor to the global epidemic of overweight and obesity, which significantly increases the risk of chronic non-communicable diseases such as type 2 diabetes, cardiovascular disorders, hypertension, and certain cancers. Both general and central obesity are associated with adverse metabolic outcomes, emphasizing that not only total body fat but also its distribution is critical for health risk assessment. In India, rising trends in overweight and obesity reflect a combination of dietary transitions, sedentary lifestyles, genetic predisposition, and behavioral factors.

Evidence suggests that prevention and management of obesity require a multifaceted approach, including moderation of caloric intake, consumption of nutrient-dense foods, portion control, and alignment of energy intake with physical activity. Behavioral strategies such as mindful eating, reducing sedentary time, and gradual, sustainable weight loss are essential for long-term weight maintenance. Monitoring body weight and central adiposity using BMI and waist circumference, respectively, provides a practical method to identify at-risk individuals and guide interventions.

In conclusion, addressing overeating and promoting energy balance at individual and population levels are critical strategies to prevent overweight and obesity, reduce associated health risks, and improve overall public health outcomes. Integrating dietary, behavioral, and lifestyle modifications under professional guidance can effectively mitigate the growing burden of obesity in India and worldwide.

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Pesticide Pollution and its Impact on Aquatic Biodiversity: A Review

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Abstract

The increased production of high-yield crops necessitates the excessive use of pesticides and fertilizers to protect crops from pests, thereby ensuring the quality of the crop. The uncontrolled and careless application of pesticides results in the pollution of the aquatic environment through multiple sources like runoff, spray drift, and leaching. This pollution presents substantial health peril for both aquatic life and mankind. Direct exposure to pesticides can lead to significant impacts across various levels of biological organization, affecting primary producers like plants, microorganisms, invertebrates, and fish in aquatic ecosystems. These impacts may disrupt the balance of the ecosystem, affecting biodiversity and overall ecological health. Additionally, it can also have indirect effects on higher trophic levels, including predators and ultimately, human beings through the food chain. This review encompassed the categorization of pesticides, their harmful impacts on aquatic organisms and habitats as well as potential remedial approaches to alleviate their toxicity. Moving forward, further research is crucial to explore inventive strategies in modern agriculture that can reduce the reliance on chemical pesticides.

Keywords: Pesticide pollution; Sources; Classification of pesticides; Aquatic toxicity; Bioremediation

1. Introduction

Pesticides are a vital tool in modern agriculture, aiding in pest control and ensuring optimal crop yields (Popp et al., 2013). However, the unintended consequences of pesticide use extend far beyond their intended targets. Pesticide runoff, the process by which these chemical compounds are carried away from agricultural fields and into nearby water bodies, poses a significant threat to aquatic biodiversity. The prolific utilization of pesticides in agriculture has led to an increase in their prevalence in our ecosystems. Rainfall, irrigation, and surface runoff transport these chemicals, along with sediment and nutrients, into streams, rivers, lakes, and coastal areas. This runoff can exert deleterious effects on the intricate balance of aquatic ecosystems and the myriad organisms that dwell within them (Grzywacz et al., 2014). Aquatic biodiversity plays a crucial role in maintaining the health and stability of ecosystems.

Fish, amphibians, invertebrates, and other aquatic organisms form intricate food webs and contribute to nutrient cycling, water quality regulation, and overall ecosystem functioning. However, when pesticides enter water bodies through runoff, they can have profound impacts on the organisms that rely on these habitats for survival. The consequences of pesticide runoff on biotic diversity in aquatic ecosystems can be far-reaching. Pesticides may directly harm or kill aquatic organisms, particularly sensitive species such as fish, amphibians, and crustaceans. They can disrupt reproductive systems, impair growth and development, and weaken immune responses, making affected organisms more susceptible to disease and predation. Furthermore, pesticides can indirectly impact aquatic biodiversity by disrupting the intricate relationships within ecosystems (Ekström and Ekbom, 2011). They may harm non-target organisms, including beneficial organisms like pollinators and natural predators pivotal in pest population management. This disturbance can trigger cascading repercussions across the food chain, leading to the disproportion and potential declines in populations of certain species.

In addition to their immediate impacts, pesticides can persist in aquatic environments, accumulating in sediments and entering the food chain. This bioaccumulation can result in long-term exposure for organisms at higher trophic levels, including larger fish and predatory birds, further amplifying the potential harm to aquatic biodiversity. The intricate nature of pesticide runoff and its ramification on the biotic diversity of aquatic ecosystems necessitates immediate attention and implementation of efficient management strategies. Understanding the specific risks associated with different pesticide types, their persistence, and their interaction with aquatic ecosystems is crucial for developing mitigation measures and sustainable agricultural practices. In this article, it was tried to explore the various ways in which pesticide runoff affects aquatic biodiversity. We will examine specific examples of harm to different species and discuss the potential long-term consequences for ecosystem health.

2. Classification of pesticides

Pesticides can be classified based on their chemical nature, intended species and applications. Intended species categories include Insecticides, herbicides, fungicides, rodenticides and insect repellents. Application pesticides are categorized as agriculture, domestic and public health pesticides. Whereas by chemical nature pesticides can be categorized as Organochlorines, Organophosphate, Carbamates, Pyrethroid, Phenyl amides, Phenoxyalkonates, Triazines, Benzoic acid, and Glyphosate.

Table 1. Classification of the pesticides based on chemical nature and composition (Jayaraj et al., 2016)

Name	Class of pesticide	Purpose of use	Side effect
DDT	Organochlorines	Insecticide	Seizures, lethargy, and confusion in humans; In birds causes eggshell thinning; in salmons causes impairment of behavioral development
Benzene hexachloride (BHC)	Organochlorines	Used as insecticide	Damage of the central nervous system, Seizures, itching and skin rashes in humans.
Lindane	Organochlorines	Used as both insecticide and rodenticide	Responsible for the damage to the immune system and the central nervous system, causing reproductive defects, cause damage to the liver, and kidneys in human.
Heptachlor	Organochlorines	Used as insecticide	induce eye irritation
Carbofuran	Carbamates	Used to kill insects and nematodes	Responsible for a respiratory disorder
Pyrethrin	Pyrethroids	Use as insecticide	Paralysis in organisms, headache, vomiting, loss of consciousness, toxicity in mammals.
Methyl parathion	Organophosphate	Insecticide Repellant	Cause respiratory problems
Malathion	Organophosphate	Used to control and kill mites (Acari) and insects	Diarrhea, blurred vision respiratory disorder
Propachlor	Acylanalide	Use to kill weeds (herbicide)	Respiratory disorder

3. Sources of Pesticide pollution:

There are numerous ways in which pesticides enter into the ecosystem. Runoffs from agriculture fields, lawns, gardens, wastewater treatment plants, pesticide factories and golf courses are some of the sources of pesticide pollution. The excessive use of pesticides in the agriculture field for crop production results in the leaching and washing of these harmful chemicals with rainfall or irrigation into the nearby ecosystems. Residential areas and golf courses also contribute a substantial amount of pesticides pollution in the ecosystem. The two main drivers for the runoff are rainfall and irrigation which transport these harmful chemicals into streams, rivers, and lakes, and other aquatic water bodies. The persistent nature of these chemical pesticides poses a long-term risk of accumulation and toxicity in the ecosystem and living organisms.

4. Global trends in pesticide utilization

Annually, twenty million tonnes of chemical pesticides are utilized worldwide. Within this total, the United States accounts for 24% of pesticide consumption, while 45% is utilized in Europe (Abhilash and Singh, 2009). Developed nations utilize pesticides enormously and countries like North Western Europe, Japan, and the United States jointly contribute approximately three-quarters of the overall pesticide global consumption (Alavanja, 2009). In these nations, herbicides are predominantly used owing to their reduced risk of causing acute poisoning compared to insecticides. On the other hand, developing countries, including India and neighbouring nations, use

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a lesser amount of pesticides when compared to highly developed economies (Wilson and Tisdell, 2001; US EPA, 1998).

Pesticide production in India commenced in 1952, initiated with the production of BHC and DDT. Over the years, pesticide production experienced substantial growth which is evident from the progressive increase in the amount of pesticide production. By 1958, the country's pesticide production surpassed 5000 MT, which escalated to 85000 MT in the mid-1990s, coinciding with the registration of 145 different varieties of pesticides. Notably, insecticides comprise a substantial proportion of the pesticide produced in India which reflects their significant role in pest control (Gupta, 2004). India holds a prominent stature in the Asia continent, being counted as a leading pesticide-producing nation, with an annual production of 9000 tonnes, positioning it as the 12th largest global player in pesticide production (Khan et al., 2010). In the past, India extensively employed and exported organochlorine pesticides, encompassing compounds like DDTs and HCHs (Pozo et al., 2011).

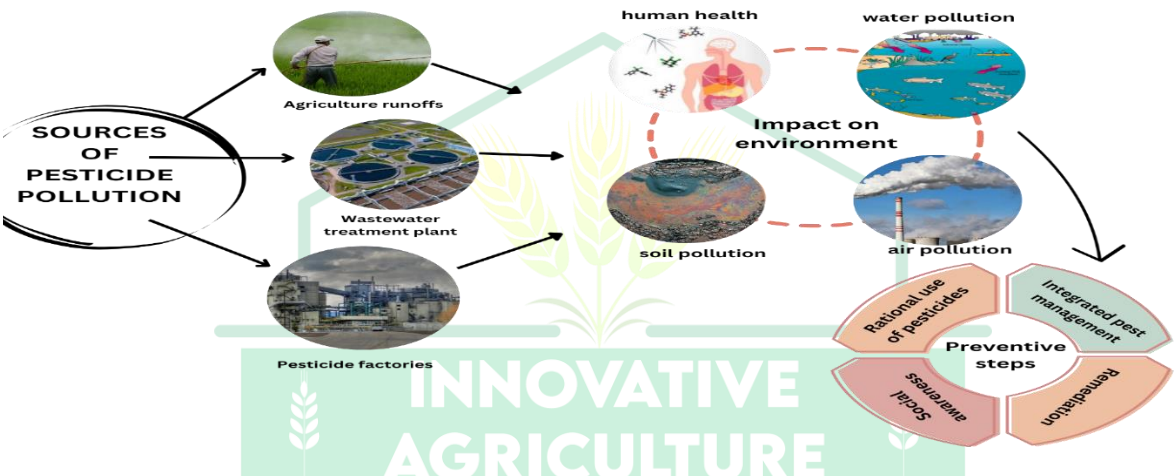

Fig. 1. Sources, impact, and prevention of pesticide pollution

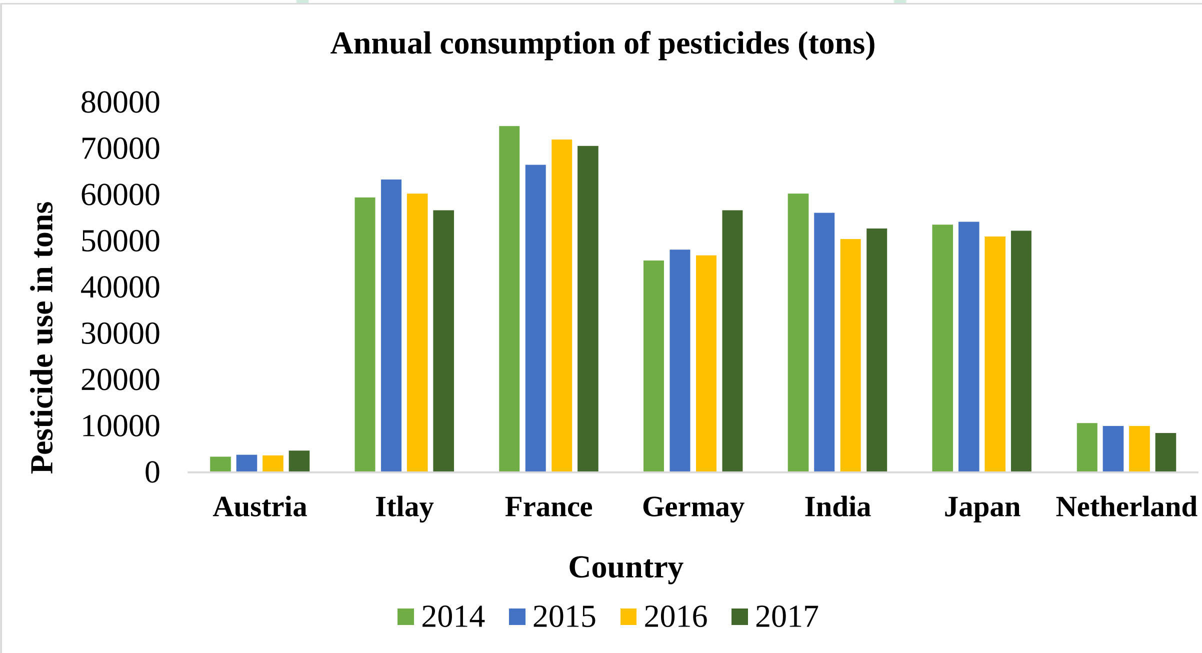

Fig. 2. The graph presents the annual pesticide consumption in India and neighboring countries (Source: https://www.fao.org/faostat).

5. Toxicity of Pesticides to Aquatic Organisms:

Pesticides can direct exert toxic effects on a wide array of water-dwelling creatures like fish, amphibians, and invertebrates. These chemicals can enter water bodies through runoff or spray drift and adversely affect the health and survival of aquatic species (Bach et al., 2001).

Direct Toxic Effects: Pesticides, especially those designed to target pests, can be extremely lethal to unintended organisms in aquatic environments. Fish, amphibians, and invertebrates are particularly vulnerable to the toxic effects of pesticides. Exposure to pesticides can lead to acute toxicity, which can cause immediate harm and even death to aquatic organisms. Pesticides can interfere with vital physiological processes, disrupt cellular functions, and impair organ systems in these species.

Impact on Growth, Development, and Reproduction: Pesticides can also have sub-lethal effects on aquatic organisms, impacting their growth, development, and reproductive capabilities. Sub-lethal exposure to pesticides can alter the growth patterns of fish and amphibians, leading to reduced size and impaired development. Pesticides can interfere with hormonal regulation, disrupt reproductive behaviours, and cause abnormalities in the reproductive organs of aquatic organisms. These effects can ultimately impact the reproductive success and population dynamics of affected species (Sabra and Mehana, 2015).

5.1 Toxic effect of pesticides on the fishes

Pesticides have many detrimental effects on the health of the fish. Exposure to pesticides is responsible for disturbing normal physiological and metabolic functions along with that it can also pose lethal toxicity to exposed organisms (Pazhanisamy and Indra, 2007; Ullah and Zorriehzahra, 2015). The toxicity of pesticides can lead to various effects such as cancer development, endocrine disturbances, genetic mutation, abnormalities in reproduction, tissue damage, behavioural changes, and haematological disorders (Ullah and Zorriehzahra, 2015; Maurya and Malik, 2016). Examining histological changes in the fish tissues is one of the important parameters for assessing the toxic effects of the pollutants. Exposure to pesticides is responsible for the damage to the various organs and systems in the fish which gives insight into the severity of the toxic effect of pesticides. When the fish is exposed to the pesticide it leads to the production of free radicles and reactive oxygen species (ROS) due to which the usual cell structure of the tissue gets disrupted, resulting in several histopathological alterations (Sepici-Dinçel et al., 2009)

- **Histological changes in the gills**

  The gills are the vital organ for carrying out the survival processes in fish such as execration, osmoregulation, and respiration (Evans et al., 2005). Gills are highly sensitive to pesticides and act as the biomarker for aquatic pollution as it has a large surface area that is in contact with contaminant present in the water (Au, 2004). Some of the common alterations that occurred in the fish gills due to pesticide exposure are abnormal bleeding in the gill structures, clubbed gill filaments, and structural damage to gill rakers. A study revealed that exposure to deltamethrin can cause excessive cell proliferation, cell death, aneurysm, and swelling due to fluid accumulation in common carp (*Cyprinus carpio*) and mosquito fish (*Gambusia affinis*) (Cengiz, 2006; Cengiz and Unlu, 2006). Another study showed the effect of gammalin 20 on the gills of African catfish in the form of abnormal gill structure and fusion of gill lamellae (Ezemonye and Ogbomida, 2010).

- **Histological changes in the liver and kidney**

  Both the liver and kidney of fish play a vital role in maintaining the internal balance and also detoxifying the fish's body. Pathological studies on the renal and liver tissues provide valuable information regarding the extent of toxicity of the pollutants in the aquatic environment (Rohani, 2023). The kidney is an organ for eliminating the toxic xenobiotic and histological alteration occurs in kidney tissues when fish is exposed to pesticides (Ortiz et al, 2003). A study conducted showed that the pesticide diazinon is responsible for the bleeding in kidney tissue and hypertrophic glomeruli in African catfish (*Clarias gariepinus*) (Al-Otaibi et al., 2018). Another study revealed that exposure to fungicidal pesticides in rainbow trout led to inflammatory changes and cell death in the kidney tissues (Boran et al., 2012). The fish liver plays a crucial role in the detoxification of contaminants and is considered an important parameter to assess the impact of contaminants on the fish's health. In banded gourami (*Trichogaster fasciata*) exposure to thiamethoxam leads to hepatic tissue necrosis, hepatic vacuolation, and liver enlargement whereas exposure to chlorpyrifos is responsible for the hypertrophic hepatocytes, abnormal nuclear condensation, hepatic scarring, and hypertrophic hepatocytes in tilapia (Hasan et al., 2022; Subburaj et al., 2020). Thus histological observations and studies are good parameters to assess the toxic effects of pesticides on fish health and environmental well-being.

- **Histological changes in gonads**
  Multiple pesticides are reported to cause various negative and unwanted effects on the reproductive health of fish species. Research has claimed that exposure to pesticides leads to damage to the ovaries of female fish in the form of abnormal yolk, degenerative changes in follicular cells and disrupted cytoplasm (Banaei et al., 2008). When Gangetic mystus (*Mystus cavasius*) was exposed to the cypermethrin pesticide doses it results in the formation of folds in oocytes and anomalies in the walls of the oocyte and granulosa layer (Uddin et al., 2022) whereas the diazinon caused adverse effects on the testes of male fish it results in lower sperm count and inflamed seminiferous tubules (Banayi et al., 2009; Dutta and Meije, 2003). Thus pesticide exposure adversely affects and damages the reproductive organs in the fishes which is responsible for the lower quality of early fish development stages such as spawn and larva.
- **Hematological and Biochemical Changes Induced by Pesticide Toxicity in Fish**
  In fish, various hematological and biochemical changes take place when it is exposed to the toxicants such as pesticides. The commonly studied haemato-biochemical parameters are based on the erythrocytes, leucocytes, and thrombocyte counts. Pesticide toxicity can be responsible for anemia and oxygen deficiency, characterized by decreased levels of hemoglobin and erythrocytes in the blood, coupled with elevated erythrocyte sedimentation rates (ESR). These effects can be attributed to a marked reduction in the production of red blood cells (erythropoiesis) and an increase in the breakdown of red blood cells (hemolysis). For instance, exposure to the pesticides such as chlorpyrifos, sumithion, and profenofs was responsible for lowering the level of red blood cells and hemoglobin in Nile tilapia (Sharmin et al., 2021; Ghayyur et al., 2019; Khan, 2019) whereas in *Mystus keletius*, exposure to the pesticide, ekalux leads to a decreased level of red blood cells and increased level of white blood cells and mean corpuscular hemoglobin (Barathinivas et al., 2022). Similarly, fenitrothion exposure elevated the blood glucose and white blood cell levels in stinging catfish (Ritu et al., 2022). Kole et al. (2022) reported that exposure to the sumithion results in a decreased level of red blood cells, hemoglobin, and glucose in *Barbonymus gonionotus.* Ullah et al. (2014) reported that exposure to the cypermethrin pesticide elicited substantial alteration in the enzymatic activities in various tissues such as the liver, brain, gills and muscle of *Tor putitora*.
- **Genetic changes induced by pesticide exposure**
  The exposure of fish to various pesticides has adverse effects on the genetic makeup of the fish. The toxic effect is attributed to the DNA and chromosomal aberration which is responsible for mutation in fish species. A study has reported that when *Channna punctatus* comes in contact with a very small amount (0.01 mg/l) of dichlorvos leads to damage to the genetic makeup of the fish in the form of the formation of gaps and breaks in chromatid and centromere, fragmentation of chromosomes, and condensation of chromatin structure (Rishi and Grewal, 1995). Another pesticide cypermethrin, exposure caused changes in the DNA and RNA of the gonadal tissue of *Colisa fasciatus* (Singh et al., 2010). Çavas and Könen. (2007) reported that when goldfish (*Carassius auratus*) were exposed to various concentrations of glyphosate leads to a concentration-dependent increase in nuclear damage and breakages in DNA strands.
- **Changes in the behavioural pattern of fish**
  Pesticide exposure is expressed in various ways in fish behaviour such as inducing lethargy and hampering their normal swimming pattern which renders them to increased predation. Exposure to such substances is also responsible for reduced feeding, fish are unable to maintain their position in the water, disrupt their swimming and schooling behaviour, and guard their areas (Nagaraju et al., 2011; Prashanth et al., 2011; Gill and Raine, 2014). Fishes also experienced compromised immunity and thus become susceptible to infections and diseases when exposed to pesticides (Satyavardhan, 2013). A study revealed that exposure to methyl parathion doses in *Catla catla* leads to the disruption of equilibrium and balance, alteration of body hue, abnormal movement of gill cover (operculum), and escalated mucus production (Ilavazhahan et al., 2010). Pesticides also interfere in the migratory movement of fish for example in Salmons they hampered the movement from freshwater to the ocean and thus normal life cycle is disturbed (Nagaraju et al., 2011).

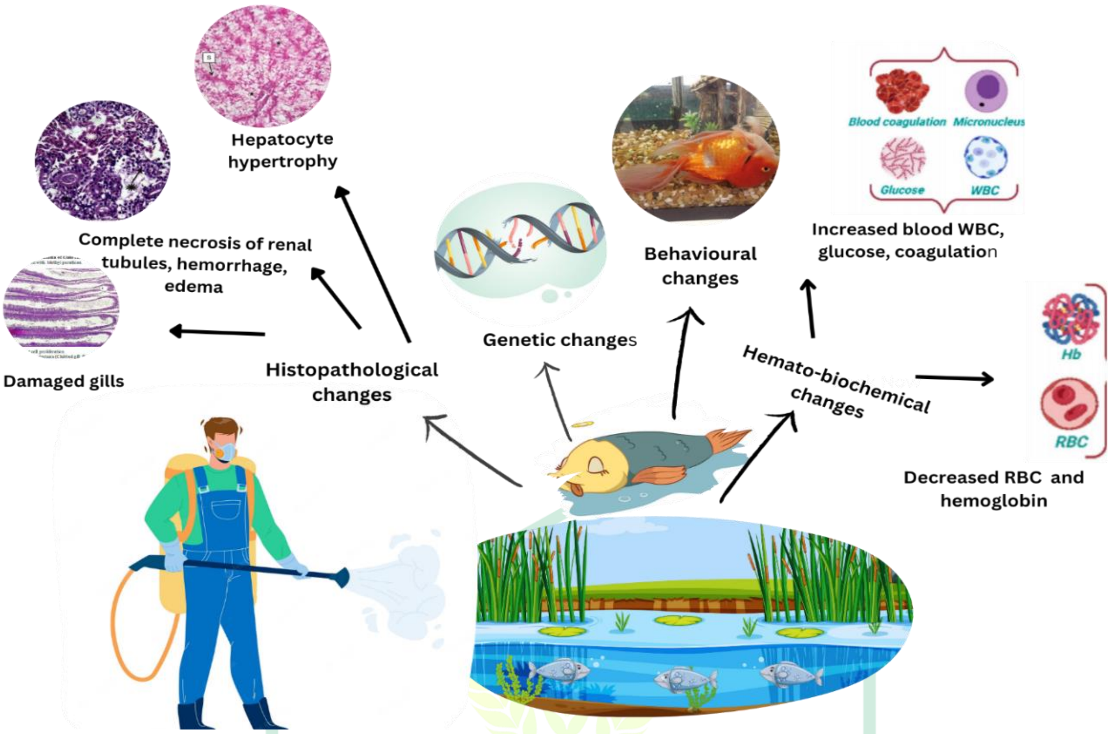

Fig. 3. Toxic effect of pesticide exposure on fish health

6. Impact on ecology:

Pesticide runoff disrupts aquatic ecosystems by degrading water quality, reducing habitat complexity, and diminishing biodiversity. Pesticides bioaccumulate in aquatic organisms, leading to trophic magnification and toxic effects on higher predators. Reduced prey availability and habitat degradation, particularly the loss of hydrophytes and microhabitats, further destabilize food webs and impair ecological processes. The overall impacts of pesticide contamination result in population declines, loss of species diversity, and altered energy flow within aquatic ecosystems. Implementing best practices in pesticide management and habitat restoration is essential to protect these ecosystems from long-term damage.

8. Analytical method for detection of pesticides

Pesticides have become a prominent factor in modern agriculture practices; however, their extensive application has led to the contamination and pollution of various ecosystems. Pesticides and their metabolized by-products can accumulate in tissues of plants, soil, and water, necessitating periodic monitoring and inspection of the environment and food. Various traditional and modern techniques, such as spectrometry, chromatography, immunoassays, and biosensors, have been employed to detect pesticides in food and the environment. Extensive experiments have been conducted on pesticide analysis in food and environmental samples. Gas chromatography (GC) is extensively applied for pesticide analysis, especially for non-polar and highly volatile compounds. Coupling GC with advanced detectors like an electron capture detector, nitrogen phosphorus detector, flame ionization, and flame photometric detector enhances sensitivity and selectivity (Słowik-Borowiec et al., 2015; Blankson et al., 2016; Farajzadeh et al., 2016; Mahpishanian et al., 2015; Rani et al., 2021). Gas chromatography-mass spectrometry (GC-MS) gives even greater sensitivity and specificity (Han et al., 2018). On the other hand, high-performance liquid chromatography (HPLC) is an excellent method for detecting a wide array of compounds like pesticides, including polarized and heat-vulnerable pesticides (Bidari et al., 2011). Liquid chromatography-mass spectrometry (LC-MS) is the most sensitive and selective approach for pesticide detection. ELISA is a rapid and cost-effective technique for pesticide detection. It offers good sensitivity and selectivity based on antigen-antibody interactions, making it ideal for specific types of pesticides. Its main advantage is the simple sample preparation process (Ahn et al., 2011).

Advanced methods based on biosensors offer an alternative to traditional techniques for pesticide diagnosis (Songa and Okonkwo, 2016). Although conventional chromatographic approaches are accurate and reliable, they are characterized by being time-intensive, highly expensive, and require large volumes of organic solvents. Biosensors provide simple, fast, and cost-effective options for in-situ monitoring with adequate sensitivity and selectivity for pesticide detection. Developing nations may benefit from these advanced techniques, which have shown promising results in various studies (Zhao et al., 2015; Bucur et al., 2018).

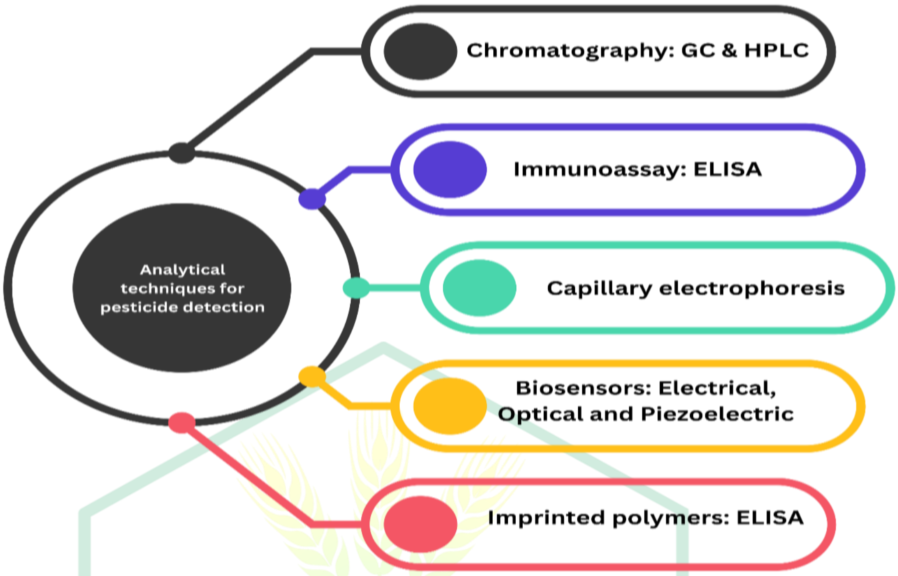

Fig. 4. Analytical methods for detecting pesticides.

9. Techniques for the mitigation of pesticides from the environment

Remediation techniques can be categorized into three main groups: biological processes, chemical processes and physical processes. Biological processes, also known as bioremediation, in which simpler products like water and carbon dioxide are formed from the more complex organic substances. This can be accomplished through microorganisms or advanced natural attenuation methods, as well as the application of bio-stimulation and bio-augmentation strategies. Physical processes utilize materials such as activated charcoal, zeolite, clay, and polymer-based materials to facilitate remediation. On the other hand, chemical reactions involve converting highly toxic compounds into less toxic forms.

- **Bioremediation**
  Bioremediation represents an environmentally friendly and economically viable technique for removing pesticides from pollutant sites without generating toxic by-products. Microorganisms play a vital function in converting pesticides into non-toxic products, making them suitable for on-site contaminant breakdown. The isolation of microorganisms can be done from various sources, such as sludge, soil, sediment, resistant insects, and fermented products (Tian et al., 2018; Zhu et al., 2016). Fungal strains and bacteria have also been employed for pesticide biodegradation (Maqbool et al., 2016). In bioaugmentation, external microorganisms possessing specialized catabolic abilities are added to contaminated sites or bioreactors to initiate the bioremediation process (Perelo, 2010). Biostimulation involves providing appropriate conditions and nutrients to support the growth of locally available microbes for efficient pesticide degradation (Trindade et al., 2005).
- **Adsorption**
  Adsorption is an effective and eco-friendly technique for pesticide removal, producing minimal by-product waste and being cost-effective. Various adsorbents like activated charcoal, clay, nanomaterials, and biochar have been used to adsorb pesticides from polluted environments. The adsorption mechanism involves chemical bonding through Van Der Waals forces, dipole-dipole interactions, ion-dipole interactions, covalent bonding and cation exchange, as well as physical adsorption (Rashed, 2013). Activated charcoal is favored due to its high surface area and adsorption capacity. Biochar, a carbon-rich material formed by pyrolyzing biomass, possesses high pore volume and surface area, rendering it highly efficient in the removal of

pesticides (Wang et al., 2018; Suo et al., 2019). Other materials like clay and zeolite have also been applied for pesticide removal from polluted environments.

Table 2. Different microorganisms are used for the removal of the pesticide from the water and soil environment.

Environment	Pesticide name	Microorganisms use for bioremediation	Remark	Reference
Water	Prometryne	*Chlamydomonas. reinhardtii*	66% degradation achieved after 6 days	Jin et al. (2012)
	Malathion	*Nostoc muscorum*	91% degradation achieved after 20 days	Ibrahim et al. (2014)
	Malathion	*Spirulina platensis*	54 % degradation was achieved in 20 days of treatment.	Ibrahim et al. (2014)
Soil	Methoxychlor	*Actinobacteria*	56.4% methoxychlor was removed from the soil	Fuentes et al. (2014)

- **Advanced oxidation processes**

  Advanced oxidation processes (Fenton process, plasma oxidation, ozonation, and photocatalytic reaction) have shown promising potential for the removal of pesticides from contaminated soils. These processes facilitate the degradation of pesticides into less harmful compounds like carbon dioxide, water, and inorganic substances. The attractiveness of these techniques lies in their ability to operate at ambient temperature and pressure, making them feasible for pesticide removal in contaminated environments (Cheng et al., 2016). Nonetheless, the research on oxidative processes is still in its nascent phase, and the scalability and cost optimization of these techniques remain to be addressed. Further exploration and research in this area are warranted.

11. Conclusion:

Pesticide runoff poses a major threat to the aquatic environment, contaminating water bodies and endangering aquatic biodiversity. Various sources like agriculture and residential areas contribute to this issue, with rainfall and runoff transporting pesticides into rivers and lakes. The persistence of pesticides worsens the problem, calling for urgent action to address the environmental impact. Pesticides have direct toxic effects on aquatic organisms, affecting fish, amphibians, and invertebrates, while also impacting growth, development, and reproduction. Commonly used pesticides demonstrate known effects on aquatic life, highlighting the need for precaution and sustainable alternatives. Pesticide runoff disrupts aquatic food webs, causing bioaccumulation in higher trophic levels and leading to ecological imbalances. Reduced prey availability and potential population declines of aquatic predators underscore the extensive implications on aquatic ecosystem structure and function. Urgent measures are needed to address the far-reaching consequences of pesticide runoff. Pesticide runoff has detrimental effects on aquatic habitats, degrading water quality, and contaminating drinking water supplies. Loss of aquatic vegetation and habitat complexity has severe consequences for biodiversity, impacting the survival and reproduction of species. Mitigation and solutions require a multifaceted approach. Adopting eco-friendly and sustainable agricultural practices, such as integrated pest management and precision application techniques, can minimize pesticide use and runoff. Buffer zones, riparian vegetation, and constructed wetlands act as natural filters, reducing the transport of pesticides into water bodies. Furthermore, public education, policy support, and the exploration of environmentally friendly alternatives are essential components of effective mitigation strategies. Addressing pesticide runoff's impact on aquatic biodiversity demands collaboration from farmers, policymakers, researchers, and the public. Raising awareness, promoting sustainable practices, and fostering cooperation can mitigate pesticide runoff, preserve aquatic ecosystems and ensure a sustainable future for generations to come.

Declaration of competing interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
Acknowledgment
The authors confirm being the sole contributor to this work and have approved it for final publication.

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Microbial Bio-control: Mechanisms and Applications in Plant Disease Management

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Microbial Bio-control:

Microbial bio-control refers to the deliberate use of microorganisms or their metabolic products, such as toxins, enzymes, or secondary metabolites, to suppress or manage harmful organisms including insect pests, plant pathogens, nematodes, and weeds. This eco-friendly strategy exploits the natural antagonistic potential of beneficial microorganisms to reduce the dependence on chemical pesticides and maintain ecological balance.In a broader sense, microbial bio-control encompasses the use of microbial inoculants or consortia that can suppress one or more types of plant diseases. This may involve the introduction of specific microbial strains (such as *Trichoderma*, *Pseudomonas*, *Bacillus*, or *Beauveria*) into the rhizosphere or phyllosphere to inhibit pathogens through mechanisms like competition, antibiosis, parasitism, or induction of systemic resistance in the host plant. Alternatively, it may also include soil management practices that enhance the activity and diversity of indigenous beneficial microorganisms, thereby leading to general disease suppression in cropping systems.

In a more specific or “narrow” context, biological control can be defined as the suppression of a particular pathogen or pest species by a single antagonistic microorganism within a defined agroecosystem. Such targeted interactions often involve well characterized bio-control agents and are designed for predictable and reproducible disease management under field conditions.

Microbial bio-control thus serves as a cornerstone of sustainable agriculture by integrating biological principles into pest and disease management. It not only minimizes environmental pollution but also improves soil health and promotes plant resilience, contributing significantly to the goals of integrated pest management (IPM) and long term agricultural sustainability.

Interactions involved in bio-control mechanisms:

From the plant’s perspective, biological control represents a favorable outcome arising from a complex network of specific and nonspecific interactions among plants, pathogens, and microorganisms in their environment. These interactions may lead to either direct suppression of pathogens or the enhancement of plant defense mechanisms. The major types of interactions involved in microbial bio-control include parasitism, antagonism, competition, and predation.

1. Parasitism:

Parasitism is a biological relationship in which two phylogenetically unrelated microorganisms coexist over an extended period, with one organism (the parasite) deriving benefit at the expense of the other (the host). In the context of bio-control, hyperparasitism, where one microorganism parasitizes a plant pathogen, plays a significant role. For example, species of *Trichoderma* and *Pythiumoligandrum* are known to parasitize fungal pathogens, thereby reducing their infective potential. Interestingly, infection of plants by mild or avirulent pathogens can also induce systemic resistance in the host, offering protection against subsequent attacks by more virulent pathogens. Thus, parasitism contributes both directly (through pathogen destruction) and indirectly (through host defense activation) to biological control.

2. Antagonism (Amensalism):

Antagonism occurs when one microorganism produces metabolites or substances that inhibit or kill other microorganisms, leading to an unfavorable effect on the latter. These inhibitory substances include antibiotics, hydrogen cyanide, siderophores, volatile compounds, and organic acids. For instance, *Bacillus subtilis* and *Pseudomonas fluorescens* secrete antibiotics such as iturins and pyoluteorin that suppress various soilborne pathogens.A simple example of antagonism at the biochemical level is the inhibition of *Nitrobacter* by ammonia released during protein and amino acid decomposition. Such antagonistic interactions form a cornerstone of microbial biocontrol, reducing pathogen populations in the rhizosphere.

3. Competition:

Competition refers to the rivalry among microorganisms for limited resources such as nutrients, space, and infection sites. Nonpathogenic or beneficial microbes can effectively out-compete pathogens for essential nutrients like iron (through siderophore production) or carbon sources in the rhizosphere, thereby limiting pathogen establishment. For example, Pseudomonas spp. producesiderophores with higher affinity for iron than those produced by many pathogenic fungi, thus depriving them of this vital nutrient.This competitive exclusion mechanism is one of the most common and ecologically sustainable forms of biological control in natural and agricultural systems.

4. Predation:

Predation involves the active killing and consumption of one microorganism by another for nutrition and survival. Although the term "predator" is traditionally used for higher organisms, several microorganisms and soil mesofauna also exhibit predatory behavior. Examples include protozoa that feed on bacterial or fungal pathogens and fungal feeding nematodes or micro-arthropods that reduce pathogen biomass. For instance, the ciliate *Didiniumnasutum* preys upon Paramecium, illustrating microbial-level predation that can influence microbial population dynamics in the soil.

Biological control can arise from any of these interactions, parasitism, antagonism, competition, or predation, depending on the environmental and ecological context in which they occur. However, significant and consistent bio-control effects are most often achieved through the manipulation of beneficial plant microbe mutualisms and the antagonistic activities of microbes against pathogens. Understanding and harnessing these natural interactions form the foundation of sustainable and ecologically sound plant disease management strategies.

Advantages and limitations of Microbial Bio-control:

The use of microbial agents for pest and disease management offers several ecological and economic benefits compared to conventional chemical-based control methods. However, their successful application also poses certain limitations that need to be addressed for large scale adoption.

Advantages	**Limitations**
Environmentally safe and biodegradable	Effectiveness influenced by environmental conditions
Highly target-specific	Narrow host range limits broad application
Low cost of production	Viability and storage issues in tropical climates
Supports sustainable agriculture	Requires precise application timing
Reduces pesticide use	Regulatory hurdles for commercialization

Applications in Plant Disease Control:

Microbial bio-control agents play a crucial role in suppressing a wide range of plant diseases caused by fungi, bacteria, and other soilborne pathogens. Their effectiveness arises from diverse mechanisms such as antibiosis, competition, parasitism, and induction of systemic resistance.

Bio-control Agent	**Target Pathogen(s)**	**Host Crop(s)**
Trichodermaharzianum	*Rhizoctoniasolani*, *Sclerotiumrolfsii*	Cereals, pulses, vegetables
Pseudomonas fluorescens	*Pythium* spp., *Fusarium* spp.	Rice, tomato, chickpea
Bacillus subtilis	*Alternaria* spp., *Botrytis* spp.	Cotton, vegetables, fruits
Beauveriabassiana	*Helicoverpaarmigera*, whitefly	Cotton, vegetables
Metarhiziumanisopliae	Termites, locusts	Sugarcane, maize, horticultural crops

Mechanisms of Bio-control:

Microbial bio-control agents suppress plant pathogens through a variety of direct and indirect mechanisms. These mechanisms include competition for nutrients and space, antibiosis, mycoparasitism, stimulation of host plant resistance, and synergistic interactions among metabolites and enzymes. Each of these contributes uniquely to the overall effectiveness of biological control in agricultural ecosystems.

Mechanism	**Description**
Antibiosis	Production of antibiotics, toxins, or volatile compounds inhibiting pathogens.
Competition	Microbes compete with pathogens for nutrients (e.g., iron) and space.
Parasitism	Direct attack and degradation of pathogen cell walls by enzymes.
Predation	Consumption of pathogens by protozoa or other microorganisms.
Induced Systemic Resistance	Activation of plant defense pathways against future infections.

Examples of commercial bio-control formulations available in India:

Product Name	**Microbial Agent**
Bio-Cure B	*Bacillus subtilis*
Ecofit	*Trichodermaviride*
Bio-Guard	*Pseudomonas fluorescens*
Green Guard	*Beauveriabassiana*
Bio-Power	*Metarhiziumanisopliae*

Conclusion:

The effectiveness of microbial bio-control agents lies in their ability to integrate several mechanisms simultaneously, making them versatile and resilient tools in sustainable plant disease management. Understanding these interactions at the molecular and ecological levels is essential for optimizing their use in Integrated Pest Management (IPM) and for developing next generation bio-control formulations.

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The Golden Crop: How Mustard is Revolutionizing

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Abstract

As Indian agriculture faces mounting challenges from water scarcity, soil degradation, and climate variability, mustard (*Brassica juncea*) is emerging as a sustainable, science-backed solution rooted in tradition. Cultivated for over 5,000 years, mustard now covers 6–7 million hectares across India, offering a powerful combination of drought tolerance, soil-restorative properties, and economic versatility. This article explores mustard's agronomic strengths—from deep taproots and natural biofumigation to climate resilience—and its expanding role in oil production, biodiesel, and global markets. Scientific studies reveal how mustard enhances nitrogen cycling, supports pollinators, and outperforms water-intensive crops like wheat. Despite facing pest pressures and policy neglect, innovations such as GM mustard and CRISPR-based breeding are reshaping its future. Bridging ancient wisdom and modern biotechnology, mustard stands poised to become the flagship crop of India's sustainable farming revolution.

1. Introduction

In the parched landscapes of India, where shrinking water tables and depleted soils threaten food security, farmers are embracing an age-old ally with renewed relevance: mustard. Cultivated for over 5,000 years, with roots tracing back to the Indus Valley Civilization, mustard is now witnessing a powerful resurgence. India has emerged as the world's second-largest mustard producer, after Canada, covering 6–7 million hectares annually (FAO, 2023). What sets mustard apart is its unique combination of drought resilience, low input demands, and remarkable soil-rejuvenation properties—features now being backed by agricultural science.

Mustard's journey from ancient fields to modern farms mirrors India's own shift toward sustainability. Ancient texts such as the Charaka Samhita highlighted its medicinal value, while today's journals celebrate its allelopathic and agronomic benefits. Unlike water-intensive crops, mustard thrives with just 300–400 mm of rainfall, making it ideal for rainfed areas like Rajasthan, Uttar Pradesh, and Haryana. Its short 110–120-day growth cycle also allows efficient crop rotation with wheat, promoting soil health and long-term productivity.

Modern research reveals why mustard excels in Indian conditions. Its deep taproot system, reaching up to 1.5–2 meters, breaks up compacted soils and accesses subsurface moisture—crucial in arid zones. Even more impressively, mustard roots secrete glucosinolates, natural compounds that suppress nematodes and soil pathogens by 30–50% (Journal of Phytopathology, 2022). Farmers in Punjab have observed up to 22% higher wheat yields after mustard cultivation, thanks to these soil-cleansing effects. It also uses 40% less irrigation than wheat while delivering similar economic returns, boosting both resource efficiency and profitability.

Economically, mustard is a versatile crop offering dual yields: nutritious edible oil and protein-rich meal. Valued at ₹35,000 crore annually, the mustard oil industry is growing steadily, despite competition from imported oils. Innovations are expanding its scope—from biodiesel (1 tonne of seeds yields 400 liters of fuel, as shown by IIT Delhi research) to specialty varieties for export markets. Environmentally, mustard supports pollinators, increasing honeybee colony strength by 30% during flowering, as per the All India Coordinated Project on Honeybees.

Table 1. Agronomic and Biochemical Properties of Indian Mustard

Parameter	Value/Range	Scientific Basis	Implications
Glucosinolate Content	80–120 µmol/g DW	ICAR-IARI (2021)	Suppresses soil pathogens via biofumigation
Water Use Efficiency	2.4–3.1 kg/mm water	PAU Ludhiana (2022)	Requires 40% less irrigation than wheat
Root Depth	1.5–2.0 m	CRIDA Hyderabad (2020)	Deep rooting enhances drought resilience
Erucic Acid (Old Varieties)	40–50% of oil content	FSSAI Standards (2023)	Subject of health debates
Erucic Acid (New Varieties)	<2% (CRISPR-edited)	ICAR-NIPB Trials (2023)	Meets global food safety standards
Nitrogen Contribution	50–100 kg N/ha	Indian Journal of Agronomy (2022)	Reduces need for synthetic fertilizers
Thermal Tolerance	10°C–35°C (optimal)	IARI Climate Studies (2023)	Well-suited to North Indian winters
Seed Oil Content	38–42%	DRMR Bharatpur (2023)	Strong economic potential

2. Mustard's Agronomic Science: Why It Thrives in India

A. Soil Health and Biofumigation Superpowers

Mustard significantly improves soil health through its unique biochemical properties. Its roots secrete glucosinolates—sulfur-rich compounds that act as natural biofumigants. According to ICAR-IARI research, these compounds reduce soil-borne pathogens by 30–50% (Journal of Phytopathology, 2022), offering a sustainable alternative to chemical fumigants. Farmers across mustard-growing regions report fewer instances of root rot and wilt in subsequent wheat crops.

Mustard also stands out for its water efficiency, making it a lifeline for water-stressed regions. Trials by Punjab Agricultural University show that mustard requires 40% less irrigation than wheat while providing similar economic returns. This efficiency is driven by:

- A deep taproot system (1.5–2 meters), accessing subsurface moisture.
- A waxy leaf coating, reducing water loss through evaporation
- A short growing cycle (110–120 days), avoiding peak summer heat

B. Built for India's Climate Challenges

Mustard is ideally suited to the rabi season of North India due to its robust temperature tolerance:

- Optimal growth occurs between 10–25°C, perfectly aligning with Indo-Gangetic winter conditions
- Frost tolerance enables it to survive brief dips to -4°C
- Heat tolerance in varieties like RH-0749 allows it to withstand up to 35°C during pod development

Its drought tolerance is another key strength:

1. A strong taproot-lateral root network for enhanced water uptake
2. Osmotic adjustment through proline accumulation to retain cell turgor
3. Stomatal control to minimize moisture loss during midday heat

Field trials in Rajasthan show that mustard yields remain stable even with a 30% rainfall deficit, outperforming other rabi crops like chickpea and lentil. This combination of soil-building traits and climate resilience reinforces mustard's status as a strategic crop for unpredictable agro-climatic conditions.

Table 2. Mustard Pest Management: Scientific Solutions

Pest/Disease	Yield Loss	Scientific Intervention	Efficacy
Aphids	30–35%	RH-725 (resistant) + 5% neem oil spray	70–80% control
White Rust	25–40%	NRCHB-506 (resistant)	85% reduction
Alternaria Blight	20–30%	Bacillus subtilis biocontrol	60–70% suppression
Sclerotinia Rot	15–25%	Mustard–wheat–mungbean crop rotation	50% lower incidence

3. Mustard as a Cover Crop: Triple Benefits for Sustainable Farming

Weed Warrior: A Natural Herbicide Alternative

Mustard acts as a potent smother crop, suppressing weed growth through fast canopy development and biochemical interference. Research from ICAR-DWR Jabalpur found a 60% reduction in weed biomass in mustard fields compared to fallow land. Its effectiveness comes from:

- Rapid emergence within 3–4 days, outpacing weeds
- Allelopathic compounds that inhibit weed seed germination
- Dense foliage, achieving 90% ground cover in just 30 days

This reduces herbicide use by 2–3 sprays per season, saving ₹800–1,200 per acre and enhancing soil health.

Nitrogen Bank: The Power of Green Manure

Incorporating mustard biomass into the soil provides a significant fertility boost:

- Releases 50–100 kg of nitrogen/ha, equal to 2–3 bags of urea
- Raises soil organic carbon by 0.2–0.5% in a single season
- Enhances microbial activity, with 30% higher bacterial populations

Farmers practicing mustard–wheat–mungbean rotations report 15% higher wheat yields due to this nitrogen enrichment (Indian Journal of Agronomy).

Pollinator Paradise: Supporting Biodiversity

Mustard's bright yellow blossoms attract pollinators, making it a bee haven:

- Each hectare supports 5–7 honeybee colonies
- Increases honey yield by 25–30 kg per colony
- Enhances pollination in neighboring crops, with a 15% boost in fruit set in orchards

Farmer Spotlight: Gurpreet Singh's Water-Smart Switch

"After watching groundwater fall by 10 feet in just five years, I replaced rice with mustard on my 8-acre Punjab farm. Now I use 60% less water, spend less on weed control, and earn ₹42,000/acre from mustard oil—plus my wheat yield has improved!"

His story echoes a wider trend, with over 12,000 hectares in Punjab shifting from rice to mustard cultivation to conserve water while maintaining profitability.

4. Economic and Scientific Potential: Oil, Biodiesel, and Global Markets

A. Mustard Oil: India's Liquid Gold

India consumes 2.5 million tonnes of mustard oil annually (APEDA, 2023), making it the world's largest consumer. Yet the industry faces a nutritional dilemma:

- Traditional value: Rich in monounsaturated fats (60%) and vitamin E
- Scientific debate: Tension between FSSAI's erucic acid limits (<5%) and Ayurveda's support for its health benefits
- Market demand: Despite challenges, mustard oil commands a premium at ₹120–150/liter vs. ₹80–100 for palm oil

The advent of GM Mustard (DMH-11) could transform the sector by:

✓ Increasing yields by 25–30%

✓ Reducing import dependency (India imports 60% of edible oils)

✓ Potentially saving ₹15,000 crore annually in foreign exchange—though public safety concerns remain a hurdle

B. Global Trade: Expanding Footprint

Mustard exports rose by 18% in 2022–23, with major buyers including the UAE (40%), Nepal (25%), and the USA (15%). Exported products include:

- De-oiled cake for livestock feed (₹22,000/tonne)
- Specialty mustard varieties for gourmet markets (20% annual growth)
- Organic mustard oil, fetching 3x premiums in the EU

Innovation is driving the future, with efforts focused on:

- Breeding low-erucic acid varieties to meet global food standards
- Promoting winter mustard in Africa using Indian cultivars
- Earning carbon credits for mustard-based biodiesel systems

Table 3. Mustard vs. Competing Oilseeds: Key Scientific Metrics

Trait	Mustard	Soybean	Sunflower	Groundnut
Water Requirement	300–400 mm	500–600 mm	450–550 mm	500–700 mm
Oil Yield (L/ha)	400–450	350–400	500–550	600–650
Protein Content (Meal)	25–30%	40–45%	15–20%	25–28%
Soil Carbon Sequestration	0.5–0.8 t CO_2/ha/yr	0.3–0.5	0.2–0.4	0.4–0.6
Climate Resilience	High (drought-tolerant)	Moderate	Low (heat-sensitive)	Moderate

5. Challenges and Innovations: Securing Mustard's Future

A. Battling Biotic Threats

Mustard crops face significant biotic stress, leading to yield losses of **30–35% annually** (IIMR, Bharatpur). The major culprits include:

- **Aphids**: These sap-sucking insects can colonize 90% of a field within two weeks.
- **White rust** (*Albugo candida*): Causes characteristic white pustules and stunted growth.
- **Alternaria blight**: Leads to premature leaf drop and reduced photosynthetic area.

Science-backed solutions include:

1. **Resistant varieties**: RH-725 (aphid-tolerant), NRCHB-506 (rust-resistant)
2. **Bio-pesticides**: Neem oil reduces pest load by up to 50%, while *Trichoderma* seed treatment offers disease control
3. **AI & Smart Monitoring**: Pheromone traps and mobile alert systems are enabling precision pest management through early warnings

B. Cutting-Edge Innovations

India's public and private sectors are pushing mustard innovation through advanced technologies:

Breakthroughs include:

- **CRISPR gene editing**: ICAR-NIPB is developing low-erucic acid (<2%) mustard lines
- **Nano-fertilizers**: Increase nutrient use efficiency by up to 30% (IARI trials)
- **Drone phenotyping**: Multispectral imaging helps detect crop stress and nutrient deficiencies early

Startup-driven innovations:

- **Mustard Milk**: A Bengaluru-based company is developing plant-based dairy alternatives
- **Bioplastics**: A Delhi startup is converting mustard stalks into biodegradable plastic substitutes

The road ahead requires:

1. Wider adoption of Integrated Pest Management (IPM)
2. Policy realignment in favor of climate-resilient crops
3. Scaling precision farming tools to maximize efficiency and sustainability

6. Conclusion: Mustard – The Crop of India's Sustainable Future

As Indian agriculture faces the dual threats of climate change and soil degradation, mustard emerges as a time-tested yet futuristic solution. This humble crop is proving to be a multi-dimensional asset:

- Revitalizing degraded soils via natural biofumigation
- Conserving scarce water resources through deep-rooted drought resilience
- Enhancing farm incomes with dual-purpose output—oil and meal
- Supporting biodiversity by boosting pollinator health

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