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A STEP TOWARDS AGRICULTURE

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"Integrated aquaculture harmonizes fish, crops, and environment into a sustainable cycle of food and livelihood"

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"INTEGRATED AQUACULTURE SUSTAINS LIFE BY HARMONIZING FISH, CROPS, AND ENVIRONMENT INTO ONE PRODUCTIVE CYCLE"

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Integrated Aquaculture is emerging as a sustainable and innovative approach to food production, combining aquaculture with agriculture and other allied practices to maximize resource efficiency. Unlike conventional systems, integrated aquaculture utilizes natural ecological linkages—for instance, recycling pond water rich in nutrients for crop irrigation, or using livestock manure to enhance pond productivity. Such systems not only improve overall farm output but also reduce environmental impact, minimize input costs, and diversify farmers' income sources.

As global demand for food and fish protein continues to rise, integrated aquaculture offers a pathway to enhance food security while maintaining ecological balance. It represents a harmony between traditional wisdom and modern science, ensuring optimum use of land, water, and biological resources.

From a socio-economic perspective, integrated aquaculture provides resilience to small-scale farmers by reducing risks associated with market fluctuations or climate variability. By diversifying production, farmers are less dependent on a single commodity and can ensure year-round income and nutrition. Additionally, such systems support rural employment, women's participation in farming activities, and community-level self-reliance. In many developing regions, integrated aquaculture has proven to be a low-cost, high-return strategy that aligns with both traditional farming knowledge and modern sustainable development goals.

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Integrated Aquaculture

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Kiranjeet Kaur

Assistant Professor, Sri Guru Granth Sahib World University, Punjab

Integrated aquaculture is a farming approach where fish rearing is combined with other agricultural or livestock enterprises such as poultry, dairy, piggery, goat, or duck farming. Instead of treating each activity separately, they are linked together so that the by-products or wastes from one system become inputs for another. This method not only makes better use of available resources but also ensures sustainability, profitability, and environmental balance.

Significance of Integrated Aquaculture

Efficient Resource Utilization

One of the key advantages of integrated aquaculture is the effective recycling of farm waste. Manure from animals such as ducks, chickens, cattle, or pigs is applied to fish ponds, where it acts as an organic fertilizer. This natural fertilization encourages the growth of plankton, which becomes a direct food source for fish. In this way, the same land and water generate multiple products, fish, eggs, milk, meat, and manure, without a significant increase in production costs.

Cost Reduction and Environmental Sustainability

By using livestock manure and crop residues in ponds, farmers reduce their dependence on costly fish feed and chemical fertilizers. Farm resources are reused within the system, lowering expenses while minimizing waste. This recycling also helps prevent water and soil pollution, cuts down on chemical use, and maintains ecological balance in the farming environment.

Economic Benefits and Income Diversification

Integrated aquaculture offers farmers several income streams, reducing the risk of financial loss. Unlike traditional farming, where dependence on a single commodity can be risky, integrated systems spread the risk across different enterprises. Farmers can earn through:

- Sale of fish, either fresh, dried, or processed.
- Daily or weekly sale of poultry or duck eggs.

- Regular income from milk produced by cows, buffaloes, or goats.
- Meat from goats, poultry, pigs, or ducks, which has high market demand.
- Manure and other farm by-products, which can be used in fields or sold.

This diversification provides financial stability throughout the year, even if one component underperforms.

Role in Food and Nutritional Security

Integrated aquaculture also strengthens food availability and nutrition for rural communities.

- Fish supply high-quality protein, essential fatty acids, and minerals such as calcium and phosphorus.
- Eggs from ducks or poultry are rich in protein, vitamins (A, D, B12), and minerals like iron and selenium.
- Milk from dairy animals offers calcium, vitamin D, and easily digestible proteins.
- Meat from goats, pigs, and poultry provides energy-rich protein and essential amino acids.

Together, these products help combat malnutrition, especially protein-energy deficiency and micronutrient shortages in vulnerable populations.

Regular Supply of Food

Milk and eggs provide a daily or weekly food source, while fish and meat add variety and bulk during seasonal harvests. This continuous supply ensures that families have access to essential foods even during lean agricultural periods.

Resilience in Times of Crisis

In situations such as drought, crop failure, or sudden price fluctuations in grain markets, integrated aquaculture serves as a safety net. Even if one component of the farm system is affected, other sources of food and income remain intact. This resilience makes farming households more secure and less vulnerable to external shocks.

Types of Integrated Aquaculture Systems

1. Poultry–Fish Culture in Integrated Aquaculture

Concept and Process

In this system, poultry birds such as chickens, quails, or sometimes ducks are reared in sheds located either along the pond embankment or directly above the pond. Their droppings, which are rich in nutrients, either fall straight into the water or are collected and applied in measured quantities. Poultry manure contains high levels of nitrogen and phosphorus, which stimulate the growth of phytoplankton and zooplankton in the pond. These microscopic organisms form the natural food base for fish species like carps, tilapia, and catfish, thereby enhancing overall pond productivity.

Ecological Role

The manure from poultry acts as an organic fertilizer for pond water, promoting the natural food chain by increasing plankton populations. This recycling of farm waste reduces the dependence on external fertilizers and helps maintain a more sustainable and eco-friendly farming environment.

Economic Role

This integration offers farmers dual benefits. Poultry provides a quick return in the form of eggs and meat, which can be sold regularly, while fish offer seasonal or annual income during harvest. This ensures a continuous income cycle with both short-term and long-term financial returns. Moreover, poultry houses can be constructed on pond dikes or above the water, making efficient use of limited land resources. Poultry litter, when dried, can also be utilized as an organic fertilizer for field crops, adding another source of value.

Advantages

- It enhances pond productivity naturally without relying on chemical fertilizers.
- It ensures a steady market supply of poultry products such as eggs and meat.
- Poultry manure can be repurposed for use in crop cultivation.
- It allows maximum use of limited farm space, especially beneficial for smallholders.

Challenges and Limitations

- Excess poultry waste can over-fertilize the pond, leading to algal blooms, oxygen depletion, and even fish mortality.
- Disease outbreaks such as Newcastle disease or coccidiosis can spread quickly among poultry if proper hygiene and biosecurity measures are neglected.
- Incorrect stocking density or over-application of manure can disturb pond ecology.
- Accumulated poultry waste may attract flies and other pests, creating management challenges.

Best Management Practices

- To maintain an optimal bird density of about 500–700 birds per hectare of pond.
- Ensure regular cleaning of poultry sheds and proper vaccination of birds to prevent diseases.
- Remove excess litter frequently and compost it before use to avoid water pollution.
- Keep sheds well-ventilated and maintain hygiene to control pests.
- Monitor pond water quality on a weekly basis to ensure a healthy environment for fish.

2. Duck–Fish Culture in Integrated Aquaculture

Concept and Process

In this system, ducks are reared directly on fish ponds or in floating sheds placed above water. As they move and feed, their droppings fall into the pond. Since duck manure is rich in nitrogen and phosphorus, it acts as a natural fertilizer for the pond water. These nutrients stimulate the growth of plankton—both phytoplankton (algae) and zooplankton (tiny crustaceans and protozoa)—which serve as natural feed for fish. Species such as Rohu, Catla, Mrigal, Tilapia, and Pangasius thrive well under this arrangement because they feed efficiently on these plankton populations.

Ecological Role

The presence of ducks benefits the pond ecosystem in several ways. Their constant paddling keeps the water in gentle motion, which improves aeration and maintains dissolved oxygen levels. Ducks also serve as natural pond cleaners since they consume insects, weeds, and snails that otherwise compete with or harm fish. This natural cleaning reduces the need for chemical inputs and helps sustain a healthy pond environment.

Economic Role

Duck–fish culture allows farmers to generate multiple income sources. Ducks provide a steady daily income through egg sales and additional earnings through meat sales when culled. The feathers and manure can either be used on the farm or sold for extra revenue. At the same time, fish harvesting brings seasonal profits. This diversification ensures that farmers have both short-term and long-term income security throughout the year.

Advantages

- The pond area is utilized for multiple outputs—fish, eggs, meat, and manure.
- Dependence on costly commercial fish feed and chemical fertilizers is reduced, as ducks naturally supply manure and food resources for fish.
- Land use efficiency increases because the same pond space supports both aquaculture and poultry farming.
- Farmers and their families benefit from a supply of protein-rich foods while also earning from the market.

Challenges and Limitations

- Overstocking ducks can lead to excess manure in the pond, which may reduce oxygen levels and cause water quality issues.
- Ducks are prone to diseases like avian influenza, and if hygiene is poor, pathogens may spread to pond water, endangering fish.
- Predators such as snakes can attack both ducks and fish.
- Stocking density must be managed carefully; about 200–300 ducks per hectare of pond is generally considered safe for maintaining balance.

Best Management Practices

- Construct duck houses along the pond's edge so that manure input into the water can be better regulated.
- Rotate ducks in and out of ponds to allow water quality to recover naturally.
- Vaccinate ducks regularly to prevent disease outbreaks.
- Monitor water quality parameters such as oxygen and nutrient levels to keep the pond environment stable.

3. Dairy–Fish Culture in Integrated Aquaculture

Concept and Process

In this system, dairy animals such as cows or buffaloes are kept close to fish ponds so that their dung and leftover feed can be efficiently utilized. Cow dung, when added to the pond, decomposes gradually and releases nutrients that stimulate the growth of phytoplankton and zooplankton. These organisms serve as natural food for fish species like Common carp, Grass carp, Rohu, and Catla, thereby improving overall pond productivity.

Ecological Role

Cow dung acts as a slow-release organic fertilizer, which keeps the pond fertile for a longer duration compared to fast-acting poultry manure. Along with this, uneaten cattle fodder also breaks down and adds to the nutrient pool, further encouraging plankton growth. This promotes a stable ecological balance within the pond.

Economic Role

This integration allows farmers to earn daily income through milk sales and seasonal income from fish harvests, ensuring financial stability. In addition to milk, dairy farming provides other valuable products like butter, ghee, curd, and manure, further boosting income. The system also supports recycling, as nutrient-rich pond silt mixed with cattle manure can later be applied to crop fields, enhancing soil fertility and reducing dependence on synthetic fertilizers.

Challenges and Limitations

- Requires relatively more land to maintain both a cattle shed and a fish pond together.
- Excess or uncontrolled disposal of dung into the pond can cause nutrient overloading, eutrophication, and oxygen shortage.
- Regular cleaning of cattle sheds is necessary to avoid contamination of both feed and water.
- Health management is crucial, as diseases such as mastitis in dairy animals or parasitic infections in fish can affect production.

Best Management Practices

- Apply dung in controlled quantities (about 500–1000 kg per hectare per month) and preferably use composted dung to avoid water pollution.
- Keep cattle in hygienic conditions and ensure timely vaccination to prevent disease.
- Monitor pond health regularly, especially oxygen levels, and watch for stress symptoms in fish such as surface gasping.

4. Goat–Fish Culture

Goat farming can be effectively integrated with fish culture to improve resource use and farm income. The droppings from goats, when applied to ponds, act as organic manure that enriches the water with nutrients and promotes plankton growth. This natural food base supports the growth of fish species such as Rohu, Catla, and Tilapia.

Alongside fish production, farmers also benefit from goat milk and meat, which ensures additional earnings. However, goats must be managed carefully—pond embankments should be fenced to prevent damage, and waste should be applied in regulated amounts to avoid water pollution.

Best Management Practices for Integrated Aquaculture

To achieve maximum benefits from integrated aquaculture, the following practices are recommended:

1. **Proper Site Selection**: Choose farm locations with a dependable water source and suitable drainage to maintain pond health.
2. **Suitable Species Combination**: Select fish species that can efficiently utilize nutrients released from livestock manure, ensuring compatibility between both components.
3. **Manure Handling**: Apply droppings in controlled quantities to prevent excess nutrient buildup, which can cause oxygen shortages and water pollution.
4. **Disease Prevention**: Maintain cleanliness and regular health checks for both livestock and fish to minimize disease outbreaks.
5. **Balanced Stocking Density**: Keep appropriate numbers of fish and livestock to avoid overcrowding and ensure healthy growth.
6. **Monitoring and Record-Keeping**: Track production, feeding, and health data to improve farm efficiency and make timely management decisions.

Conclusion

Integrated aquaculture systems, such as duck–fish, poultry–fish, dairy–fish, goat-fish combinations, offer a practical and sustainable approach to farming. These systems make efficient use of resources by recycling waste products, thereby reducing environmental impact while enhancing productivity. Farmers benefit not only from diversified sources of income but also from improved household nutrition and food availability. When supported with proper knowledge, training, and good management practices, integrated aquaculture can significantly contribute to rural livelihoods, environmental protection, and the overall growth of the agricultural economy.

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Brassinosteroids: Key Hormonal Regulators in Plant Stress Tolerance

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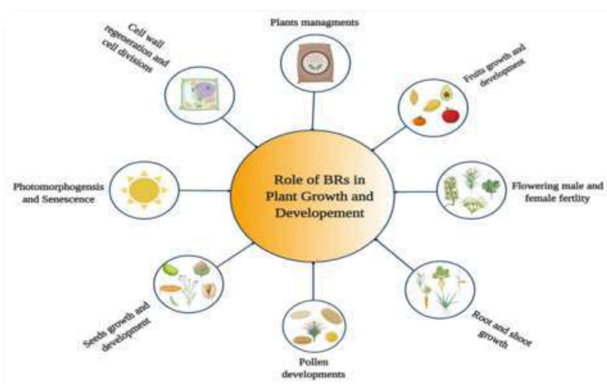
Priya Pandey[1] , R. N. Kewat[2], Sheetanu Singh[1], Garima Dixit[3],

[1]Research Scholar, Department of Biochemistry, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya

[2]Professor, Department of Biochemistry, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya

[3]Research Scholar, Department of Food and Nutrition, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya

A class of plant steroid hormones known as brassinosteroids (BRs) plays a variety of functions in the growth, development, and stress-reaction of plants. Brassinosteroids (BRs) are recognized for their significant role in mitigating stress-induced disruptions in normal plant metabolism by activating various tolerance mechanisms. Global research efforts have increasingly focused on enhancing plant growth through the exogenous application of BRs, using methods such as foliar sprays, seed priming before sowing, and incorporation into the root growth medium. Numerous studies have demonstrated that applying BRs externally to stressed plants effectively enhances their stress tolerance mechanisms. Deficits in BR affect essential physiological functions in plants and result in aberrant phenotypes. Numerous investigations demonstrate that BRs can have a beneficial impact on how plants react to abiotic stressors such heat, cold, drought, salinity, pesticides, and heavy metals. However, little is known about the underlying processes of stress tolerance caused by BR. BR stimulate BRASSINAZOLE RESISTANCE 1 (BZR1)/BRI1-EMS SUPPRESSOR 1 (BES1), transcription factors that activate thousands of BR-targeted genes. Brassinosteroids (BRs) have been shown to enhance photosynthetic efficiency under stress conditions, significantly contributing to increased plant growth and biomass accumulation. Genetic studies generally support a positive link between endogenous BR levels



and abiotic stress tolerance; however, this relationship is sometimes contradicted by the stress responses observed in certain BR mutants. Importantly, plant responses to BRs vary widely depending on species, developmental stage, and environmental conditions. Moreover, interactions with other hormones and signaling molecules are crucial in modulating BR-mediated stress responses, further influencing plant adaptation under adverse conditions. They also strengthen the antioxidant defense system, elevate enzymatic activity, and upregulate stress-responsive genes such as superoxide dismutase (SOD), peroxidase (POD), catalase (CAT), glutathione reductase (GR), and ascorbate peroxidase (APX) [17, 18]. The exogenous application of BRs has been shown to promote cucumber seedling growth under $Ca(NO_3)_2$-induced stress by improving photosynthetic capacity, reinforcing antioxidant defenses, and maintaining chloroplast ultrastructure [14]. Even under non-stress conditions, BR treatment stimulates plant growth, enhances net photosynthetic rate, and boosts antioxidant capacity, highlighting their multifunctional role in plant development. BR-insensitive mutants identified in model species such as *Arabidopsis* and *Brassica* exhibit various developmental abnormalities, including dwarfism, dark green leaves, delayed flowering, and male sterility.

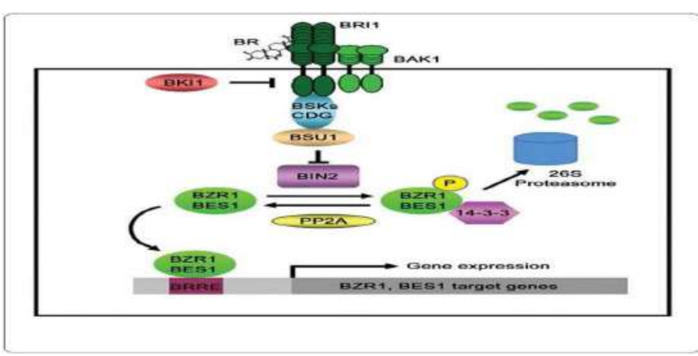


Fig 1 Structure of three common brassinosteroids

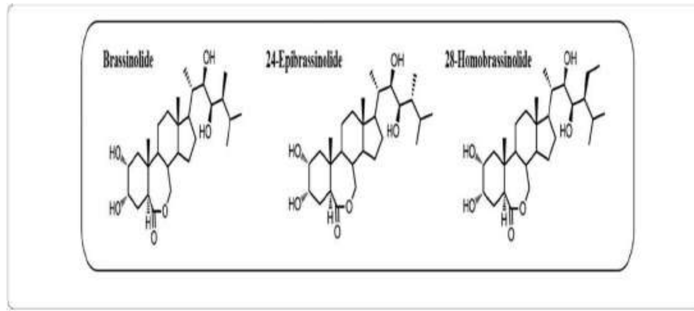


Fig :2- A model of brassinosteroid (BR) signaling in *Arabidopsis*.

Mechanisms of Brassinosteroid Action Under Stress Conditions

Cellular and molecular responses: Brassinolide, 24-epibrassinolide, and 28-homobrassinolide are among the most bioactive forms of brassinosteroids (BRs) and are commonly utilized in physiological and molecular studies . Early research has shown that BRs regulate a wide range of physiological and developmental processes across various plant species. These include cell elongation in stems and roots, leaf expansion, photomorphogenesis, flower development, male sterility, stomatal development, and enhanced resistance to environmental stress.

Regulation of gene expression

The signal transduction pathway begins with brassinosteroids (BRs) being recognized by the receptor kinase BRASSINOSTEROID INSENSITIVE 1 (BRI1) located on the cell surface, which activates the transcription factors BRASSINAZOLE RESISTANT 1 (BZR1) and BRI1-EMS SUPPRESSOR 1 (BES1) to promote stress tolerance. When BR is applied externally, it binds to BRI1, triggering its association with BRI1-ASSOCIATED RECEPTOR KINASE 1 (BAK1) and the dissociation of BRI1 KINASE INHIBITOR 1 (BKI1) . Activation of BRI1 requires sequential transphosphorylation with BAK1, which subsequently phosphorylates BR-SIGNALING KINASE 1 (BSK1) and enhances the activity of BRI1 SUPPRESSOR 1 (BSU1). Activated BSU1 inhibits BRASSINOSTEROID INSENSITIVE 2 (BIN2) by dephosphorylating a key phospho-tyrosine residue, allowing the accumulation of unphosphorylated BZR1 and BZR2/BES1 transcription factors. These dephosphorylated transcription factors then move into the nucleus, where they regulate BR-responsive genes that enhance plant stress tolerance by boosting antioxidant enzyme activity, modulating endogenous hormone levels, and upregulating thousands of target genes.

Role of Brassinosteroids in Enhancing Plant Stress Tolerance

Brassinosteroids (BRs) are plant steroid hormones that play a crucial role in regulating various physiological processes and enhancing plant adaptation to both abiotic and biotic stresses [15, 48]. Numerous studies have indicated that BRs influence the activity of defense-related enzymes and hormonal pathways during stress responses. This section highlights key physiological and molecular mechanisms through which BRs contribute to plant tolerance under different stress conditions.

Brassinosteroids and Abiotic Stress Tolerance

Chilling stress is a significant abiotic factor that adversely affects plant growth and development across many regions, disrupting various physiological processes. Exposure to low temperatures can halt plant growth, impair photosynthesis, reduce chlorophyll content, and cause flower bud abortion, ultimately leading to substantial yield and economic losses. To combat such environmental challenges, plants have evolved complex and overlapping regulatory mechanisms to respond to both abiotic and biotic stresses. Phytohormones such as brassinosteroids (BRs), salicylic acid (SA), jasmonic acid (JA), abscisic acid (ABA), and gibberellins (GA) play essential roles in stress signal transduction pathways and activation of plant defense mechanisms . Among these, BRs are particularly noted for their role in regulating plant growth and mediating a wide range of physiological responses to abiotic stresses, including both low and high temperature stress. Water availability, another critical factor for plant survival, is often inconsistent, especially in arid and semi-arid regions. Drought stress significantly hampers crop productivity by impairing antioxidant systems, reducing chlorophyll levels, affecting photosynthetic efficiency, and compromising membrane integrity . Studies have demonstrated the beneficial role of BRs in enhancing drought tolerance. For instance, in *Cicer arietinum* (chickpea), BR treatment under water deficit conditions led to notable improvements in fresh and dry biomass, tiller number, stem thickness, root activity, and nitrate reductase activity . Similarly, BR application in radish seedlings under drought conditions enhanced antioxidant enzyme activity and alleviated drought-induced damage , underscoring the protective role of BRs in water-stressed environments.

Brassinosteroids and Biotic Stress Resistance

In natural environments, plants encounter both biotic stresses, such as attacks from pathogens and pests, and abiotic stresses like extreme temperatures and salinity. To defend themselves, plants rely on an immune-like system composed of physical barriers and inducible defense mechanisms that are activated upon stress. These responses are regulated by complex signaling networks involving key plant hormones, including ABA, ethylene, jasmonic acid, salicylic acid, and brassinosteroids (BRs). BRs have been shown to improve plant growth, yield, and resistance to fungal and viral pathogens, with their effectiveness depending on the application method and timing. BRs also interact with transcription factors such as MYB30 and BES1 to regulate stress-responsive genes. In various studies, BR application has been linked to increased levels of stress-related hormones and antioxidants, particularly under conditions like chilling or pathogen attack. This indicates that BRs play a crucial role in enhancing biotic stress tolerance through hormonal crosstalk and gene regulation.

Conclusion

Brassinosteroids (BRs) are vital plant hormones that significantly contribute to growth, development, and stress adaptation. They enhance tolerance to a wide range of abiotic stresses, including drought, salinity, temperature extremes, and heavy metals, as well as biotic stresses like pathogens and pests. BRs function through complex signaling pathways, regulating key transcription factors such as BZR1 and BES1, which activate stress-responsive genes and antioxidant systems. Their interactions with other phytohormones further fine-tune plant defense responses. Both exogenous application and endogenous regulation of BRs have shown promising results in improving stress resilience and crop productivity. Overall, BRs represent a powerful tool for developing stress-tolerant crops and ensuring sustainable agricultural practices under changing environmental conditions.

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Arthropod Pests of Pulses: Biology and Control

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Anshu Kumari

Student, School of Agriculture and Environmental Sciences, Shobhit Deemed University, Meerut (U.P.)

Pulses are a vital source of dietary protein, carbohydrates, vitamins, and minerals for millions of people worldwide. They are often referred to as the "poor man's meat" due to their affordability and high protein content, especially in developing countries. Globally, pulses such as chickpea, pigeonpea, lentil, cowpea, mungbean, and common bean are widely cultivated. Besides their nutritional value, they also contribute to sustainable agriculture by fixing atmospheric nitrogen, thereby improving soil fertility and reducing dependence on chemical fertilizers. However, pulse crops are highly vulnerable to a wide range of arthropod pests. These pests not only reduce yield in the field but also cause post-harvest losses in storage. According to FAO estimates, field and storage pests together can account for 20–40% yield losses annually, with certain pests like pod borers (Helicoverpa armigera) and storage bruchids (Callosobruchus spp.) causing total seed destruction under favorable conditions. Therefore, a detailed understanding of pest biology, seasonal incidence, and control strategies is crucial for devising sustainable Integrated Pest Management (IPM) approaches.

Major Arthropod Pests of Pulses and Their Biology

1. Pod Borer (*Helicoverpa armigera*)

Biology: One of the most destructive pests globally. Female moths lay up to 1,500 eggs, mostly on flower buds, flowers, and young pods. Eggs hatch within 3–5 days. The larval stage lasts 15–20 days, during which caterpillars bore into pods and feed on seeds. Pupation occurs in soil. Life cycle is completed in 30–40 days.

Damage: Pod boring leads to unfilled seeds, characteristic circular exit holes on pods, and direct seed loss of up to 50%.

2. Aphids (*Aphis craccivora*)

Biology: These soft-bodied insects reproduce rapidly, often parthenogenetically. Colonies are found on tender shoots, leaves, flowers, and pods.

Their population builds up quickly in cool, moist weather.

Damage: Continuous sap sucking causes curling, yellowing, and stunted growth. Honeydew excretion supports sooty mold development. More importantly, aphids transmit viral diseases like Cowpea Aphid-Borne Mosaic Virus (CABMV), leading to huge indirect losses.

3. Whitefly (*Bemisia tabaci*)

Biology: Eggs are laid on the undersides of leaves. Nymphs are sedentary and suck sap continuously. Adults are small, white-winged insects capable of flying and dispersing easily.

Damage: Sap sucking weakens plants, causes yellowing, and reduces photosynthesis. Whiteflies are the primary vectors of Mungbean Yellow Mosaic Virus (MYMV), one of the most destructive viral diseases of pulses.

4. Thrips (*Caliothrips indicus, Frankliniella schultzei*)

Biology: Minute, slender insects that reproduce quickly in hot, dry conditions. They prefer flowers, tender buds, and leaves.

Damage: Scraping of tissues leads to silvering, bronzing, curling of leaves, and poor flower and pod setting. Heavy infestations cause flower shedding and low yields.

5. Bruchids (*Callosobruchus chinensis, C. maculatus*)

Biology: Major storage pests, but field infestation often begins before harvest. Females lay eggs on pods or seeds. The emerging larvae bore directly into the seed, completing their development inside. One generation takes 3–4 weeks, and several generations occur during storage.

Damage: Infested grains show exit holes and powdery residues. Seeds lose germination ability and market value. If unchecked, bruchids can cause 100% grain loss in storage.

6. Pod Bug (*Clavigralla gibbosa*)

Biology: Belongs to Hemiptera. Eggs are laid on leaves and pods. Both nymphs and adults feed by sucking sap.

Damage: Feeding causes shriveled, discolored seeds with reduced viability. Infestation also leads to flower drop and malformed pods.

7. Leaf Miner (*Ophiomyia phaseoli*)

Biology: A small fly that lays eggs in leaf tissues. Maggots mine between leaf layers, creating zig-zag patterns.

Damage: Reduces effective photosynthetic area, leading to poor plant vigor. In severe cases, defoliation occurs.

8. Armyworms and Cutworms (*Spodoptera litura, Agrotis ipsilon*)

Biology: Polyphagous pests. Females lay eggs in clusters covered with brown scales. Caterpillars feed at night on foliage and stems.

Damage: Seedling mortality, defoliation, and cutting of stems near soil level. Losses are severe during early crop stages.

9. Termites (*Odontotermes spp., Microtermes spp*.)

Biology: Social insects living in large colonies. They attack underground parts and sometimes above-ground stems.

Damage: Plants wilt suddenly, seedlings dry up, and yield reduction may exceed 20% in termite-prone areas.

Seasonal Incidence of Major Pests

- **Pod Borer**: Maximum during flowering to pod formation (October–March in subtropics; varies globally).
- **Aphids**: Appear early in crop season, thriving in cool, humid weather.
- **Whitefly:** Active during warm, dry conditions but peak populations coincide with flowering.
- **Thrips**: Abundant in hot, dry climates, especially during pre-flowering.
- **Bruchids**: Predominantly storage pests but infestation begins in the field at maturity.
- **Cutworms/Armyworms:** Damage seedlings after rains at the crop establishment stage.
- **Termites**: Active throughout season in sandy/light soils.

Integrated Pest Management (IPM) in Pulses

Cultural Control

- Early sowing to avoid pest peak periods.
- Deep ploughing to expose pupae of pod borers.
- Crop rotation with non-host crops.
- Maintaining field sanitation by removing alternate hosts and residues.
- Proper drying and storage of seeds.

Host Plant Resistance

Development of resistant varieties against pod borers, aphids, and MYMV is a cost-effective, eco-friendly approach. For example, resistant mungbean lines have shown tolerance against whitefly-transmitted MYMV.

Biological Control

- Egg parasitoids (Trichogramma chilonis) for H. armigera.
- Predators such as ladybird beetles, green lacewings, and syrphid flies for aphids.
- **Pathogens:** *Bacillus thuringiensis* (Bt) and Nuclear Polyhedrosis Virus (NPV) against pod borers.
- Braconid parasitoids (Bracon hebetor) against bruchids in storage.

Botanical Control

- Neem-based formulations (NSKE 5%, neem oil) for sucking pests.
- Sweet flag (Acorus calamus) and pongamia extracts effective in storage pest management.

Chemical Control (Judicious Use Only)

Pod borers: Emamectin benzoate, chlorantraniliprole.

Aphids/whiteflies: Imidacloprid, thiamethoxam.

Thrips: Spinosad or fipronil sprays.

Bruchids in storage: Aluminum phosphide fumigation (in airtight conditions).

Integrated Approach

- Combining resistant varieties, trap crops, biological agents, and need-based insecticide application.
- Farmer field schools and community IPM programs have shown success in Asia and Africa by reducing pesticide use by 30–40% without yield loss.

Conclusion

Arthropod pests pose a major challenge to pulse cultivation worldwide, both in the field and in storage. Understanding their biology and seasonal incidence is essential for sustainable management. While chemical insecticides provide quick results, their indiscriminate use leads to resistance, resurgence, and environmental hazards. Therefore, emphasis must be placed on eco-friendly IPM practices, including resistant varieties, natural enemies, botanicals, and cultural practices. A globally coordinated strategy is needed to manage pests like pod borers and bruchids that cause extensive losses. Adoption of climate-smart IPM will not only enhance pulse productivity but also ensure environmental safety and long-term food security.

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Role of Foliage Texture and Color in Garden Design

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Ankit Raj

Student, School of Agriculture and Environmental Sciences, Shobhit Deemed University, Meerut (U.P.)

Foliage texture and color are critical components in garden design, influencing the visual appeal, depth, and overall harmony of landscaped spaces. While flowers often capture attention, the leaves' form, pattern, and hue create the underlying structure and mood of a garden. This article explores the significance of foliage characteristics, types of textures and colors, and practical applications in landscape architecture. Strategic use of foliage enhances contrast, rhythm, and continuity, contributing to aesthetically pleasing and functional garden environments.

Garden design is a careful balance of plants, hardscape, and environmental considerations. While flowers and blooms are often celebrated, the leaves and foliage of plants provide continuity, structure, and color throughout the growing season. Texture and color of foliage affect how plants are perceived in terms of scale, distance, and focal interest. Landscape architects and gardeners use these attributes to create depth, balance, and visual contrast, thereby shaping the character and mood of outdoor spaces.

Foliage Texture in Garden Design

Texture refers to the surface quality of leaves—how they feel and appear, either to the touch or visually.

Types of Foliage Texture

Fine Texture: Leaves are small, narrow, and delicate. Examples include ferns and grasses. Fine-textured foliage creates a soft, delicate effect and can be used in the background to enhance larger forms.

Medium Texture: Most shrubs and perennials fall into this category, providing balance and versatility. Examples include boxwood and hosta.

Coarse Texture: Large, bold, or rough leaves such as banana or elephant ear plants. Coarse textures provide focal interest, dominate visual space, and create contrast with finer textures.

Role in Design

- Creates contrast and balance between different plant forms.

- Influences perceived scale; coarse textures make plants appear larger, fine textures appear smaller.
- Enhances depth and layering in garden compositions.

Foliage Color in Garden Design

Foliage color includes the hue, intensity, and variation of leaf pigmentation. Beyond green, foliage may include shades of red, purple, silver, yellow, or variegated patterns.

Applications of Foliage Color

Creating Contrast: Using contrasting colors such as red foliage against green background draws attention and highlights focal points.

Harmonizing Spaces: Similar or analogous colors create unity and calmness in garden areas.

Seasonal Interest: Colored or variegated foliage provides visual appeal even when flowers are absent.

Defining Zones: Bright or warm-colored foliage can mark entrances or pathways; cool-colored foliage can recede into the background.

Examples of Colored Foliage Plants

- Red: Japanese maple (*Acer palmatum* 'Bloodgood')
- Silver/Gray: Lamb's ear (*Stachys byzantina*)
- Yellow: Golden euonymus (*Euonymus japonicus* 'Aureo-marginatus')

Combining Texture and Color in Garden Design

Layering: Placing fine-textured plants in the background, medium textures in mid-ground, and coarse textures in foreground enhances depth.

Contrast and Rhythm: Alternating textures and colors in beds or borders creates rhythm and visual interest.

Focal Points: Bold-colored or coarse-textured foliage can serve as focal elements in formal or informal gardens.

Balance: Harmonious combinations of foliage color and texture ensure that no single element dominates disproportionately.

Conclusion

Foliage texture and color are vital in garden design, providing structure, continuity, and year-round visual interest. While flowers may be seasonal, foliage defines form, scale, and mood across landscapes. Effective use of texture and color enhances contrast, harmony, and rhythm, creating aesthetically pleasing and functional gardens. Landscape designers must carefully consider these elements when planning plant compositions to achieve balance and visual appeal.

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Transforming Agriculture: Shri Manjeet Singh's Inspiring Story of Increased Farm Profitability with Crops and Dairy

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Deepti Mayee Gochhayat*, Dr. Gurshaminder Singh

UIAS, Chandigarh University, Gharuan, Mohali, Punjab

Name: Shri Manjeet Singh

Village: Nogawan,Bassi Pathana, Fatehgarh Sahib

Age: 62

Mobile no.: 9872577808

Enterprise Adopted: Crops and Dairy

In the fertile plains of Punjab, agriculture is more than just a profession—it's a legacy. Shri Manjeet Singh, a 62-year-old farmer from Nogawan village, Bassi Pathana, Fatehgarh Sahib, Punjab, exemplifies this legacy. What started as a modest farming operation on 2 acres of inherited land has now blossomed into a thriving 10-acre integrated farm**,** combining advanced crop production and dairy farming to ensure economic sustainability and community progress.

Early Life And Beginnings

Shri Manjeet Singh was born into a farming family that owned just 2 acres, cultivating only rice and wheat using traditional methods. These practices barely met the family's needs, with low productivity and no crop variety, leaving them vulnerable to seasonal uncertainties and rising costs. Despite having only a 10th-grade education, Manjeet was determined to break free from subsistence farming. He actively sought guidance from agricultural experts and government programs, experimenting with crop diversification by adding sugarcane, sorghum, and maize. He also integrated dairy farming with 12 cows, using sorghum as fodder to feed animals. Today, his progressive efforts have transformed the farm into a thriving 10-acre operation—6 acres under direct cultivation and 4 acres leased—setting a benchmark for rural success.

Figure 1: Interaction with Shri Manjeet Singh

The Turning Point:Vision And Struggle

Shri Manjeet Singh's journey from a traditional farmer to a progressive agricultural entrepreneur began with strong determination to improve his family's financial condition. His deep understanding of farming and relentless spirit motivated him to explore new possibilities. After years of observation, experimentation, and consulting agricultural experts. Manjeet adopted a diversified cropping strategy, transforming his small farm into a modern enterprise.

With the support of government subsidies, he expanded his land holdings and invested in modern agricultural practices. Subsidies for quality seeds, machinery, and irrigation helped him bring additional land under cultivation. He introduced three high-value crops – sugarcane, sorghum, and maize – alongside traditional paddy and wheat. Sugarcane became a high-value cash crop, boosting market returns. Sorghum served as grain and fodder for livestock, while maize improved land productivity and soil health through crop rotation. Manjeet improved yields by focusing on scientific soil fertility management and balanced use of fertilizers like urea, DAP, MOP, and zinc sulfate, based on soil tests. He attended training programs and workshops organized by Punjab Agricultural University (PAU), Ludhiana, and also through KVK,etc for gaining knowledge of advanced agronomic practices, pest control, and water-saving methods.

The "Apni Kheti" mobile app became key to his success, providing real-time updates, expert advice, weather forecasts, and crop-specific guidance, helping him make timely decisions on sowing, fertilization, and harvesting. Besides crops, Manjeet expanded into dairy farming using government subsidies for milch animals, modern sheds, and fodder units, creating a sustainable dairy business. Combining government support, scientific knowledge, innovative technology, and hard work, Shri Manjeet Singh became a role model for progressive farming in rural Punjab.

Figure 2: Paddy Field

Figure 3: Maize Field

Modernization And Mechanization: Transforming Farm Efficiency

Determined to modernize his 10-acre farm, Shri Manjeet Singh invested in advanced machinery using government subsidies. He purchased two tractors and an autorikshaw for ploughing, land preparation, and transport, along with a trolley for easier crop movement. A rotavator and cultivator improved soil turning and seedbed preparation, while a leveller ensured uniform fields, optimizing irrigation and reducing water waste. He also added a large spray tank for accurate fertilizer and pesticide application. These machines reduced labor dependency, cut costs, and boosted productivity. Through mechanization, Shri Manjeet Singh transformed his farm into an efficient and progressive agricultural model.

Figure 5: Tractor and spray tanker

Figure 6: Disc harrow

Remarkable Growth And Economic Success

Today, Shri Manjeet Singh's farm has expanded into a highly productive 10-acre operation, with 6 acres under his direct cultivation and 4 acres leased in to boost output. His integrated farming approach—combining diverse crops like sugarcane, sorghum, maize, and a well-managed dairy—has significantly improved his income. His overall annual earnings now range from ₹10–12 lakhs**,** with the dairy providing a steady approx monthly income of ₹80,000–90,000**,** ensuring financial stability and growth.

Figure 7: Dairy farming

Conclusion: Inspiring Agricultural Transformation

Shri Manjeet Singh's journey from traditional farming to a progressive agricultural entrepreneur exemplifies determination, innovation, and resilience. By diversifying crops, integrating dairy farming, and adopting modern machinery, he transformed his livelihood into a successful agricultural model. Overcoming challenges with a forward-thinking mindset, he embraced knowledge and technology to improve productivity and efficiency. His success not only boosts his farm's contribution to the local economy but also inspires rural Punjab farmers to adopt modern practices. Shri Manjeet Singh stands as a role model, demonstrating that perseverance and innovation lead to sustainable growth, better livelihoods, and a brighter future for the farming community.

Farmer's Message

"My journey shows that farming is not just about tradition, but about innovation and learning. I encourage fellow farmers to explore new ideas like crop diversification and integrating dairy farming to increase income and reduce risks. Usage of scientific methods for soil health and balanced fertilizers, and take advantage of government subsidies and training programs from KVK,workshops and through agricultural universities like PAU,etc. Technology, like the 'Apni Kheti' app, provides useful real-time information to make smarter decisions. Mechanization reduces labor and boosts efficiency. Be open to change, stay determined, and adopt modern practices to transform your farm into profitable enterprise."

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Mechanical Methods of Pest Control

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Rahul Bharti

Student, School of Agriculture and Environmental Sciences, Shobhit Deemed University, Meerut (U.P.)

Pests are one of the greatest challenges in agriculture, horticulture, and storage systems as they directly affect crop productivity and quality. Over the years, various pest control measures have been developed, ranging from cultural and biological methods to chemical control. While chemical control provides quick results, its long-term drawbacks such as pesticide resistance, environmental contamination, and harm to beneficial organisms have highlighted the importance of eco-friendly alternatives.

One of the oldest and most sustainable pest management strategies is the use of mechanical control methods. These methods rely on physical actions such as hand-picking, trapping, pruning, and using barriers to prevent or reduce pest infestation. Unlike chemical pesticides, mechanical methods leave no toxic residues and are safe for humans, animals, and natural enemies of pests.

Though labor-intensive, mechanical methods are highly practical in kitchen gardens, nurseries, organic farming, and smallholder agriculture. Moreover, when integrated with biological and cultural practices, they form a strong foundation of Integrated Pest Management (IPM) strategies.

Major Mechanical Methods of Pest Control

1. Hand Picking and Destruction

Manual removal of visible pests such as caterpillars, beetles, and egg masses is one of the simplest and most widely used techniques. Commonly used in vegetable crops like brinjal, tomato, and okra to control Spodoptera litura, Helicoverpa armigera, and leaf-eating beetles. Infested fruits, shoots, and leaves are also plucked and destroyed to prevent further spread.

Example: In okra fields, removing and destroying shoots infested by shoot and fruit borer helps reduce the pest population significantly.

2. Traps for Pest Management

a. Light Traps

Installed in crop fields to attract night-flying insects such as moths, beetles, and leafhoppers. A light source attracts insects, which are then killed by falling into a container of water mixed with kerosene or detergent. Effective in reducing populations of moths such as Spodoptera, Helicoverpa, and rice stem borers.

b. Sticky Traps

- Yellow sticky traps attract sap-sucking pests like aphids and whiteflies.
- Blue sticky traps are effective against thrips.
- These traps work well in polyhouses, nurseries, and open fields.

c. Pheromone Traps

Although pheromones are chemical in nature, the traps themselves are mechanical devices. They are used for monitoring and mass trapping of moth pests like *Helicoverpa armigera, Spodoptera litura, and Plutella xylostella* (diamondback moth).

d. Pitfall Traps

Small containers sunk into the soil to trap crawling insects like ground beetles, cutworms, and termites.

3. Beating and Shaking Method

Used in field crops, fruit orchards, and vegetable crops. Plants are gently beaten or shaken so that insects hiding on leaves, branches, or stems fall onto a cloth, tray, or pan containing water and kerosene. Effective against hoppers, leaf beetles, and caterpillars.

4. Barriers and Fencing

- Physical barriers restrict the entry or movement of pests into crop fields.
- Nets and screens in nurseries and greenhouses prevent entry of aphids, thrips, and whiteflies.
- Collars around seedlings made of polythene or paper protect young plants from cutworms.
- Fencing is used to prevent entry of rodents, porcupines, wild boars, and grazing animals.

5. Trenching and Digging

Trenches dug around fields prevent the migration of hairy caterpillars, termites, and locusts. When trenches are filled with water, lime, or kerosene, they act as a lethal barrier.

Example: Hairy caterpillars migrating in groups can be trapped and destroyed by trenching around crop fields.

6. Flooding and Water Management

- Flooding fields helps to control soil-inhabiting pests like white grubs, termites, and cutworms.
- In rice fields, alternate wetting and drying can reduce populations of stem borers and planthoppers.
- Flooding is also effective against nematodes in vegetable nurseries.

7. Heat and Temperature Treatments

a. Soil Solarization

Involves covering moist soil with transparent polythene sheets during hot summer months. Trapped solar radiation raises soil temperature (45–55°C), killing soil-borne pathogens, nematodes, weed seeds, and insect eggs. Widely practiced in nurseries of vegetables and ornamentals.

b. Hot Water Treatment

Used to disinfect seeds, bulbs, and cuttings by dipping them in hot water for a specific duration.

Example: Sugarcane setts treated at 50°C for 30 minutes help eliminate scale insects and mealybugs.

c. Cold Storage and Freezing

Stored products such as grains and fruits can be exposed to very low temperatures to kill insect pests.

Example: Freezing fruits can eliminate fruit fly larvae.

8. Pruning and Destruction of Infested Plant Parts

Cutting and burning infested twigs, leaves, or branches prevents pest multiplication.

Example: Pruning mealybug-infested twigs in guava and mango reduces pest spread. Removal of galls caused by gall midges in brinjal also prevents pest establishment.

9. Mechanical Barriers in Storage

- Grains stored in airtight metallic bins prevent entry of storage pests like rice weevils and pulse beetles.
- Use of sieves and mechanical grain cleaners also helps in removing infested grains and insects.
- Double-bagging with polythene liners provides additional protection against storage pests.

10. Vacuuming and Suction Devices

- In modern protected cultivation systems, suction devices are used to physically remove pests like whiteflies, aphids, and mites from crop foliage.
- These devices reduce pest load without chemical sprays.

Advantages of Mechanical Control

- Eco-friendly and safe for humans, animals, and beneficial organisms.
- Does not leave toxic residues on crops or in the environment.
- Provides immediate reduction of pest populations.
- Ideal for organic farming and IPM-based systems.
- Cost-effective in small-scale agriculture, kitchen gardens, and nurseries.

Limitations of Mechanical Control

- Labor-intensive and time-consuming.
- Not suitable for large-scale, commercial monoculture farming.
- Requires constant monitoring and vigilance.
- Only reduces pest populations, does not completely eliminate them.
- Some methods (like solarization) are seasonal and cannot be applied year-round.

Role in Integrated Pest Management (IPM)

- Mechanical methods are considered the first line of defense in IPM. Their importance lies in:
- Reducing initial pest populations before chemical or biological control measures are required.
- Delaying pesticide application, thereby minimizing resistance development.
- Supporting organic farming practices, where chemical pesticides are not permitted.
- Enhancing sustainability by protecting beneficial insects and reducing chemical residues.

Conclusion

Mechanical methods of pest control are among the oldest and most reliable practices in agriculture. They are safe, inexpensive, and environment-friendly, making them particularly important in organic farming, protected cultivation, and smallholder agriculture. While they may not be practical for large-scale monoculture systems, their integration with cultural, biological, and chemical methods ensures a holistic pest management strategy.

Adopting mechanical control within IPM frameworks allows farmers to achieve sustainable crop protection, reduce dependence on pesticides, and safeguard the environment. In the era of eco-friendly farming, mechanical pest control continues to hold significant relevance as a cornerstone of sustainable agriculture.

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Vegetable Production Through Aquaponics

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Kavya D.O.

Ph.D. Scholar, Department of Vegetable Science, University of Horticultural Sciences, Bagalkot, Karnataka, India.

The increasing demand for food, coupled with limited land and water resources, has put pressure on modern agricultural systems. Conventional farming methods require high inputs of water, fertilizers and pesticides, often leading to soil degradation, environmental pollution and health concerns. In this context, aquaponics has emerged as a sustainable farming technique that integrates aquaculture (fish rearing) with hydroponics (soilless plant cultivation) in a closed-loop system. Aquaponics is defined as the integration of hydroponic plant production into recirculating fish aquaculture systems (Nelson, 2008). It represents a symbiotic cultivation method where plants and aquatic animals coexist in a balanced, recirculating environment. In this system, fish release nitrogenous wastes such as ammonia, which, through natural biological processes, are converted into nitrates that serve as essential nutrients for plant growth. In turn, the plants absorb these compounds, effectively purifying the water and creating a sustainable environment for the fish. This mutually beneficial relationship ensures resource efficiency, environmental balance and sustainable food production.

Concept of Aquaponics

Aquaponics is based on three key biological components:

1. Fish – Produce nitrogenous waste in the form of ammonia.
2. Plants – Uptake nitrates and grow in a soilless environment.
3. Bacteria – Convert toxic ammonia into nitrites and then nitrates, which act as nutrients for plants (Rakocy *et al*., 2013).

Working Mechanism

- Fish release ammonia-rich waste into the water.
- Nitrifying bacteria convert ammonia first into nitrites, then into nitrates.
- Plants absorb the nitrates as essential nutrients for growth.
- The water, filtered by plant uptake, is recirculated back to the fish tanks. This cycle forms a balanced ecosystem that supports both plant and animal life (Nelson, 2008).

Advantages of Aquaponics

Aquaponics is highly water-efficient, using only about 10% of the water needed in soil farming, (Somerville *et al*., 2014). while allowing dual harvests of fish and vegetables for better income. It is organic, free from pesticides and avoids soil-borne issues like weeds and diseases. Moreover, it supports a wide range of fast-growing, nutrient-demanding crops, making it climate-resilient and sustainable.

Aquaponics supports leafy greens such as lettuce, spinach, amaranthus and Chinese cabbage, along with fruiting vegetables like tomato, cucumber, pepper and eggplant. These crops grow rapidly in nutrient-rich water, achieving shorter cultivation cycles than soil farming (Goddek *et al*., 2015).

Benefits to Farmers and Consumers

For farmers, aquaponics ensures continuous production, dual income streams and reduced input costs. For consumers, it guarantees fresh, organic and nutrient-rich food without chemical residues. Additionally, aquaponics reduces environmental impacts such as water wastage, soil degradation and pollution.

Conclusion

Aquaponics represents a promising agricultural model for sustainable food production in the 21st century. Its integration of aquaculture and hydroponics ensures efficient use of resources, dual productivity and eco-friendly farming practices. As global challenges such as climate change, water scarcity and food insecurity intensify, aquaponics offers an innovative pathway toward resilient and sustainable agriculture. With further research, training and investment, this technology has the potential to transform farming systems and contribute significantly to future food security.

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Role of Environmental Factors in Pest Outbreaks

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Nargis Khatoon

Student, School of Agriculture & Environmental Sciences, Shobhit Deemed University, Meerut (U.P.)

Pests are one of the major constraints in agricultural production, responsible for significant yield reduction and economic loss worldwide. Their population dynamics and outbreak patterns are not only determined by their biology and host availability but are also heavily influenced by environmental factors. A pest outbreak can be defined as a sudden and explosive increase in pest numbers, crossing the economic threshold level, and causing serious damage to crops, forests, or stored products.

Agricultural ecosystems are highly dynamic and are affected by climatic and ecological changes. Pest outbreaks occur when favorable conditions allow insect populations to reproduce rapidly, overwhelming natural control mechanisms. Among these conditions, environmental factors such as temperature, humidity, rainfall, wind, and broader climatic changes like global warming play a pivotal role. Each factor influences insect behavior, reproduction, mortality, dispersal, and interaction with host plants and n...

Temperature

Temperature is considered the most critical environmental factor influencing insect development. Insects are poikilothermic, meaning their metabolic rate and life processes depend directly on ambient temperature. High temperatures generally shorten the development period, increase reproduction rate, and allow multiple generations per year. For example, the diamondback moth (*Plutella xylostella*), a major pest of crucifers, develops more rapidly under warm conditions, often leading to continuous infestations.

On the other hand, extremely high or low temperatures can suppress pest populations. Prolonged winters reduce survival rates of overwintering pests, while sudden heat waves may kill vulnerable stages like larvae or pupae. However, under climate change scenarios, milder winters in many regions allow greater survival of pests such as aphids, resulting in early-season outbreaks.

Humidity

Relative humidity influences pest survival, fecundity, and egg viability. Many insect pests require certain moisture levels to maintain physiological processes.

High humidity, combined with moderate temperatures, favors the multiplication of pests such as whiteflies, aphids, and mites. Similarly, fungal pathogens of plants and insects flourish under humid conditions, indirectly impacting pest-host interactions.

Excessive humidity may also create conducive environments for pests of stored grains, such as beetles and moths, to thrive. Conversely, dry conditions can suppress pest outbreaks by reducing egg hatching and increasing desiccation mortality. For instance, spider mites (Tetranychus spp.) prefer dry conditions, while other sucking pests decline in numbers during drought stress.

Rainfall

Rainfall can have dual effects on pest populations. Heavy rains may physically dislodge and wash away small pests like thrips, aphids, and whiteflies from plant surfaces, thereby reducing their populations. At the same time, rainfall promotes lush vegetative growth, providing abundant food resources for pests like grasshoppers and armyworms. Alternating wet and dry conditions create ideal circumstances for locust breeding, often triggering widespread outbreaks.

Excessive or untimely rains also lead to waterlogged fields, which favor pests like rice stem borers and planthoppers. Droughts, in contrast, may reduce some pest populations but can simultaneously weaken crops, making them more vulnerable to pest attacks.

Wind

Wind is a critical environmental factor influencing the dispersal and migration of pests. Many small-bodied insects such as aphids and whiteflies rely on wind currents for passive long-distance movement. Migratory pests like locusts and planthoppers exploit wind direction and speed to colonize new regions rapidly. In some cases, strong winds can suppress outbreaks by physically damaging or dispersing insect populations, but more often, winds aid in the spread of pests over large areas.

Climate Change

Climate change is a global phenomenon reshaping pest dynamics. Rising temperatures, unpredictable rainfall, and increased frequency of extreme weather events significantly influence pest distribution and outbreak frequency. Warmer climates are expanding the geographical range of many pests to higher latitudes and altitudes where they previously could not survive. For example, the coffee berry borer (Hypothenemus hampei), once restricted to lower altitudes, is now observed in higher coffee-growing areas du...

Similarly, invasive species like the fall armyworm (Spodoptera frugiperda) have spread rapidly across continents due to favorable environmental conditions facilitated by climate variability. These shifts create new challenges for pest management, as traditional knowledge and practices may not be sufficient in altered agro-ecosystems.

Interaction with Host Plants and Natural Enemies

Environmental factors do not act on pests in isolation; they also influence host plants and natural enemies. Drought stress weakens plants, lowering their natural defense mechanisms and making them more susceptible to pests such as stem borers. Conversely, vigorous plant growth under favorable rainfall can attract pests that thrive on tender tissues.

Similarly, predators, parasitoids, and pathogens of pests are sensitive to environmental changes. A decline in natural enemy populations due to adverse weather conditions can remove important checks on pest growth, leading to outbreaks. This imbalance is particularly visible in monoculture farming systems where biodiversity is already low.

Case Studies

- Locust swarms in East Africa and South Asia (2020) were triggered by unusual cyclonic activity and heavy rainfall, creating ideal breeding conditions.
- Brown planthopper outbreaks in Southeast Asian rice fields are linked with high temperature, high humidity, and excessive nitrogen fertilizer use.
- The pink bollworm in cotton fields has shown altered outbreak cycles under changing climate conditions, particularly in warmer regions of India.

Management Implications

The role of environmental factors in pest outbreaks underscores the importance of incorporating weather and climate data into pest management strategies. Forecasting models based on temperature, humidity, and rainfall patterns can help predict pest incidence. Farmers can take preventive actions such as adjusting sowing dates, choosing resistant varieties, or deploying biological control agents at the right time.

Integrated Pest Management (IPM) strategies should emphasize ecological approaches that enhance natural control mechanisms while reducing chemical dependency. Climate-smart agriculture, which integrates pest management with resilience-building practices, is essential to address the challenges posed by environmental variability.

Conclusion

Environmental factors play a decisive role in determining pest outbreak dynamics. From temperature and humidity to rainfall, wind, and broader climate change, these factors shape the survival, reproduction, and spread of pests in agricultural ecosystems. As climate variability intensifies, pest outbreaks are expected to become more frequent and severe. Strengthening pest forecasting, adopting IPM practices, and building farmer awareness are crucial steps toward minimizing losses and ensuring sustainable.

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Integrated Pest Management (IPM) in Cotton: A Paradigm for Sustainable Pest Control

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Dipu Kumar
Student, School of Agriculture & Environmental Sciences, Shobhit Deemed University, Meerut (U.P.)

Cotton (*Gossypium spp.*), often referred to as "white gold," is one of the most economically significant fiber crops worldwide, with over 30 million hectares under cultivation (ICAC, 2022). However, its intensive production systems are highly susceptible to a wide array of insect pests, notably lepidopteran bollworms (*Helicoverpa armigera*, *Pectinophora gossypiella*), sap-sucking insects such as aphids, jassids, and whiteflies (*Bemisia tabaci*), and invasive pests like mealybugs (*Phenacoccus solenopsis*).

Historically, pest control in cotton has relied heavily on synthetic insecticides. While initially effective, this approach has led to several negative consequences, including pest resistance, resurgence of secondary pests, reduction of beneficial insect populations, and ecological imbalance (Kranthi, 2012). These challenges necessitate a more holistic and sustainable pest management strategy—Integrated Pest Management (IPM).

IPM is a decision-support framework that integrates multiple pest control tactics—biological, cultural, mechanical, and chemical—based on ecological principles and economic thresholds. It is not merely a replacement for chemical pesticides but represents a paradigm shift towards knowledge-intensive, agroecologically sound practices (Pedigo & Rice, 2009).

Ecological and Theoretical Foundations of IPM in Cotton

IPM is anchored in ecological theories of population dynamics and trophic interactions. The core objective is to maintain pest populations below the Economic Injury Level (EIL), the point at which the cost of pest damage equals the cost of control. Economic Threshold Levels (ETLs) serve as operational triggers for intervention, ensuring that control measures are applied only when necessary (Pedigo & Rice, 2009).

The strategic framework of IPM includes:

1. **Preventive (Cultural) Practices**: Altering crop environments to make them less hospitable to pests.

2. **Biological Control**: Using predators, parasitoids, and pathogens.
3. **Mechanical And Physical Tactics**: Employing traps and manual methods.
4. **Chemical Control**: Used judiciously and only when thresholds are exceeded.

Components of IPM in Cotton Production Systems

Pest Surveillance and Forecasting

Effective IPM begins with accurate pest monitoring. Techniques include pheromone traps, yellow sticky traps, and field scouting. Digital innovations such as mobile apps, drone-based remote sensing, and AI-powered decision support systems (DSS) are increasingly being used to predict pest outbreaks and advise farmers in real time (Sharma et al., 2021). These technologies allow for precise, ETL-based interventions that prevent unnecessary pesticide use.

Cultural and Host Plant Resistance Strategies

Cultural control includes early sowing, intercropping, deep ploughing, trap cropping (e.g., with marigold or okra), and removal of alternate hosts. One of the most significant advances in cotton IPM has been the introduction of Bt cotton, which expresses insecticidal proteins from *Bacillus thuringiensis*. Bt cotton has dramatically reduced bollworm infestations (Kranthi, 2012). However, resistance has emerged, especially in *Helicoverpa armigera* and *Pectinophora gossypiella*, making resistance management strategies like refugia planting and gene pyramiding essential (Tabashnik et al., 2013).

Biological Control

Conservation and augmentation of natural enemies are central to IPM. Key predators include:

- *Coccinellidae* (ladybird beetles),
- *Chrysopidae* (green lacewings),
- Spiders (various families).

Augmentative biological control through the release of parasitoids such as *Trichogramma chilonis* and entomopathogenic fungi (*Beauveria bassiana*, *Metarhizium anisopliae*) has shown effectiveness in suppressing bollworm and sucking pest populations (ICAR, 2021). Biopesticides, especially neem-based products (azadirachtin), are gaining popularity for their environmental safety and compatibility with beneficial arthropods.

Mechanical and Physical Control

Mechanical methods include hand-picking of egg masses and infested plant parts, especially during early crop stages. Solar-powered light traps and pheromone traps offer energy-efficient monitoring and control options. Sticky traps are useful against whiteflies and aphids. While labor-intensive, these methods are particularly viable in smallholder farming systems with adequate labor availability.

Rational Chemical Use

Chemical control under IPM is a last resort. When applied, it should involve:

- Use of selective, narrow-spectrum insecticides (e.g., spinosad, flubendiamide, emamectin benzoate),
- Rotational use of insecticides with different modes of action, per IRAC (Insecticide Resistance Action Committee) guidelines, to delay resistance,
- Precise application timing and dosages to reduce non-target impacts and residue accumulation.

Outcomes and Trade-Offs of IPM Adoption

Environmental and Ecosystem Benefits

IPM enhances agroecosystem resilience by reducing pesticide load, preserving natural enemies, and supporting pollinator populations. It aligns with One Health principles by minimizing pesticide residues in food, water, and soil, and lowering risks to human health (FAO, 2020).

Economic Impacts and Social Dimensions

Studies indicate that IPM can reduce input costs (mainly insecticides) and maintain or improve yield stability (FAO, 2020). However, widespread adoption is limited by factors such as:

- Farmer knowledge and risk perception,
- Access to reliable pest diagnostics and advisory services,
- Gender roles in decision-making,
- Institutional support mechanisms (extension, subsidies, credit).

Institutional Constraints

Challenges in IPM diffusion include:

- Fragmented extension services and poor public-private coordination,
- Weak regulatory frameworks governing pesticide use,
- Inadequate investment in biocontrol infrastructure and R&D.

There is a pressing need to strengthen institutional capacity, including training, policy support, and incentivizing sustainable practices.

Future Directions and Policy Implications

To mainstream IPM in cotton production systems, the following strategies are essential:

Curriculum Integration: IPM modules should be part of national agricultural education and extension curricula.

Digital Agriculture Platforms: Encourage use of mobile DSS and remote sensing to support real-time pest advisories.

Public-Private Partnerships (PPPs): Support biopesticide development, commercialization, and quality control.

Integrated Crop Management (ICM): Combine pest management with nutrient and water optimization.

Climate-Smart IPM: Integrate IPM with broader climate adaptation strategies to address emerging pests due to global warming.

Furthermore, transdisciplinary research involving agronomists, entomologists, data scientists, and social scientists is required to develop locally adapted, scalable IPM solutions.

Conclusion

Integrated Pest Management in cotton represents a shift from input-intensive to knowledge-intensive agriculture, promoting sustainability without compromising productivity. By integrating ecological, technological, and institutional innovations, IPM has the potential to make cotton production more resilient, environmentally friendly, and economically viable.

However, achieving widespread adoption demands coordinated efforts among policymakers, researchers, extension workers, and farmers. Future progress lies in leveraging digital tools, supporting biological alternatives, and fostering participatory innovation systems that empower farmers as ecological stewards.

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Integrated Farming System (IFS)

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Loveleen Gill

Assistant professor, Department of Agriculture, Sri Guru Granth Sahib World University, Fatehgarh Sahib, Punjab

Integrated Farming System (IFS) refers to an approach where multiple agricultural activities—such as crop cultivation, livestock rearing, poultry, fish farming—and allied enterprises like horticulture, agroforestry, and beekeeping are managed within the same farm.

The roots of IFS lie in traditional agriculture, where farmers naturally combined crops and animals. However, the structured modern version of IFS developed in the mid-20th century, particularly to assist smallholder farmers in developing nations facing low yields and limited access to technology.

During the 1950s and 1960s, food shortages pushed researchers and policymakers to recommend IFS as a cost-effective way to raise productivity. By the 1970s and 1980s, many countries officially promoted IFS—India, for instance, launched a research program aimed at developing sustainable mixed farming models for small farms.

In the 1990s, environmental concerns renewed global interest in IFS. The Food and Agriculture Organization (FAO) advocated for it as a tool to achieve sustainable agriculture and rural development. Today, IFS is gaining popularity worldwide, especially among small farmers seeking higher income and eco-friendly practices.

Objectives

The primary goals of IFS revolve around sustainability, resilience, and livelihood improvement. Key objectives include:

- Income diversification: Combining crops, animals, and other enterprises provides farmers with multiple revenue streams, reducing risks from crop failure or price drops.
- Resource efficiency: Recycling of farm by-products (e.g., manure as fertilizer, crop residue as feed) ensures optimal resource utilization.
- Soil health: Practices like crop rotation and intercropping conserve soil fertility and reduce erosion.

- Biodiversity protection: Blending crops, trees, and animals encourages ecological balance and conserves natural habitats.
- Sustainability: Reducing reliance on chemical inputs, conserving water, and lowering emissions align farming with environmental goals.
- Food security: IFS boosts food output, improving availability and stability of supply.
- Farmer empowerment: By offering accessible, sustainable practices, IFS helps smallholders improve productivity, income, and quality of life.

Characteristics

IFS is defined by certain distinguishing features:

- Integration: Linking crops, animals, trees, and other enterprises within one system.
- Diversification: Including multiple enterprises (fish ponds, beekeeping, and livestock) to spread risks.
- Conservation focus: Emphasis on soil, water, and biodiversity management through eco-friendly practices.
- Efficiency: Optimizing inputs via integrated pest control, water-use planning, and organic amendments.
- Livelihood enhancement: Providing better nutrition, income security, and resilience.
- Adaptability: Building a farming system capable of coping with changing environmental and economic conditions.
- Management requirement: Successful IFS depends on good planning, record-keeping, and decision-making.
- Community benefits: Beyond individual gains, IFS supports rural development by strengthening social and economic stability.

Components and Their Benefits

An IFS combines several elements that interact to strengthen overall farm performance:

Crops: Cultivation of cereals, vegetables, pulses, fruits, and herbs through rotations or intercropping to sustain soil fertility and manage pests.

Livestock: Dairy animals, goats, poultry, and sheep supply manure, food, and income.

Agroforestry: Trees integrated into farmland provide fuel, timber, fruits, and ecological benefits such as soil and water conservation.

Fish culture: Fish farming not only offers protein but also recycles nutrients back into the farming system.

Beekeeping: Produces honey and wax while enhancing pollination and crop yields.

Vermiculture: Earthworms produce vermicompost, enriching soil organically.

Bioenergy: Farm residues and animal waste can be converted into renewable energy, reducing dependence on fossil fuels.

Advantages

The integration of these diverse enterprises offers multiple benefits:

- Enhanced soil fertility: Nutrient recycling improves soil structure and productivity.
- Stable income: Diversified activities protect against market or climate risks.
- Conservation of resources: Encourages sustainable use of soil, water, and biodiversity.

- Reduced input costs: Organic practices lessen dependence on synthetic fertilizers and pesticides.
- Food and nutritional security: Produces a wide range of food items, supporting local diets and reducing reliance on imports.
- Climate resilience: Use of hardy crop varieties, water-saving measures, and climate-smart practices enhances adaptability.
- Improved livelihoods: Farmers benefit from higher and more reliable incomes, greater food security, and enhanced social well-being.

Conclusion

Adopting multiple farm enterprises in a well-integrated manner can significantly enhance farmers' incomes and provide a more stable livelihood compared to relying on single, stand-alone enterprises, as demonstrated by this study. Although once widely practiced, the integrated farming approach began to decline after the Green Revolution of the late 1960s and further lost prominence with the onset of economic liberalization in the early 1990s. More than just a production method, the Integrated Farming System (IFS) represents a sustainable agricultural philosophy that promotes diversification, interdependence, and efficient recycling of resources. By viewing the farm as a complete ecosystem, IFS improves output per unit of land, labor, and water while supporting ecological balance and socio-economic resilience. It not only diversifies income but also ensures nutritional security, provides employment throughout the year, and helps reduce risks linked to market fluctuations and climate variability. In today's context of climate change, soil degradation, and increasing production costs, IFS emerges as a practical strategy for sustainable agricultural intensification. Its strength lies in conserving resources, utilizing farm by-products, and linking crop production with livestock, fisheries, and related activities, making it especially beneficial for small and marginal farmers. Therefore, the Integrated Farming System can be seen as a holistic solution-economically rewarding, environmentally sustainable, and socially relevant-making it a key pillar for the future of sustainable agriculture.

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Natural Enemies of Major Arthropod Pests

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Supriya Kumari Kajal

Student, School of Agriculture & Environmental Sciences, Shobhit Deemed University, Meerut (U.P.)

Agricultural production worldwide is continuously threatened by arthropod pests that feed on crops, transmit plant diseases, and cause severe yield and economic losses. The heavy reliance on synthetic pesticides to manage these pests has resulted in pesticide resistance, resurgence of pests, elimination of beneficial organisms, and environmental contamination. Therefore, the role of natural enemies in regulating pest populations is gaining increasing recognition in sustainable agriculture. Natural enemies include predators, parasitoids, and pathogens that attack and suppress insect pests without harming the environment. They form the ecological foundation of biological control and play a pivotal role in Integrated Pest Management (IPM) systems. This article provides a comprehensive review of the major groups of natural enemies, their role against common arthropod pests, their ecological importance, the benefits of their use, and challenges associated with their effective utilization. Strengthening research, farmer awareness, and mass multiplication of natural enemies can reduce chemical dependence and promote long-term agricultural sustainability.

Arthropod pests such as insects and mites are among the most damaging constraints in agriculture. Globally, more than 30–40% of crop yield losses are attributed to pest infestations each year. Farmers often depend on chemical pesticides for immediate results; however, indiscriminate use leads to several drawbacks, including pesticide residues in food, health hazards, destruction of biodiversity, and the development of resistance in pest populations.

In this context, natural enemies—which include organisms that prey, parasitize, or infect pests—offer a safe and ecologically sound alternative. Natural enemies have evolved along with pest species and play a central role in regulating their populations in natural ecosystems. Their deliberate use in farming systems is a cornerstone of biological control, an environmentally friendly approach that minimizes chemical input while ensuring long-term pest suppression.

Categories of Natural Enemies

Natural enemies of arthropod pests are broadly classified into predators, parasitoids, and pathogens. Each group functions differently in nature, contributing collectively to pest regulation.

Predators

Predators are free-living organisms that attack, kill, and consume multiple prey during their lifetime. Unlike parasitoids, which depend on one host, predators require numerous pest individuals to complete their development. Many predators are generalists, feeding on a wide variety of pest species, which makes them versatile in pest suppression.

Examples of Predators

Ladybird beetles (*Coccinellidae*): Feed on aphids, mealybugs, and whiteflies.

Lacewings (*Chrysopidae*): Larvae prey on aphids, thrips, and mites.

Syrphid flies (*Syrphidae*): Maggots are efficient aphid predators.

Spiders (Araneae): Generalist predators of moths, leafhoppers, and flies.

Predatory bugs (*Anthocoridae, Reduviidae*): Attack thrips, leafhoppers, and caterpillars.

Predatory mites (*Phytoseiidae*): Feed on phytophagous mites such as *Tetranychus urticae.*

Parasitoids

Parasitoids are insects that lay their eggs in or on the bodies of other arthropods. The developing larvae consume the host internally or externally, ultimately killing it. They are highly host-specific, which makes them reliable and safe agents for targeted biological control.

Examples of Parasitoids

Egg Parasitoids: *Trichogramma spp.* parasitize eggs of lepidopteran pests.

Larval Parasitoids: *Cotesia spp.* attack caterpillars such as Helicoverpa armigera.

Pupal Parasitoids: *Brachymeria spp.* attack pupae of lepidopterans.

Aphid Parasitoids: *Aphidius spp.* are effective against several aphid species.

Encarsia formosa: Widely used against greenhouse whiteflies.

Pathogens (*Entomopathogens*)

Pathogens are microorganisms that infect and kill insect pests. They often cause epizootics in pest populations under favorable conditions. Entomopathogens are formulated into biopesticides and sprayed like chemical pesticides, but without harmful residues.

Examples of Pathogens

Fungi: Beauveria bassiana, Metarhizium anisopliae infect whiteflies, beetles, termites, and aphids.

Bacteria: Bacillus thuringiensis (Bt) produces toxins lethal to caterpillars.

Viruses: Nuclear Polyhedrosis Viruses (NPV) and Granulosis Viruses (GV) target Helicoverpa and Spodoptera.

Nematodes: Steinernema and Heterorhabditis species kill soil-dwelling larvae.

Benefits of Natural Enemies

Environmentally safe: No chemical residues or pollution.

Sustainable: Provide long-term, self-perpetuating pest control.

Specificity: Parasitoids and pathogens often target specific pests.

Cost-effective: After establishment, they require little input.

Resistance management: Reduce the risk of pesticide resistance.

Biodiversity conservation: Protect natural ecological balance.

Challenges in Utilization

- Slow action compared to chemicals.
- Environmental dependency (temperature, humidity, pesticide residues).
- Mass production requires specialized facilities.
- Pesticide compatibility issues.
- Lack of farmer awareness and training.

Role in Integrated Pest Management (IPM)

Natural enemies are a cornerstone of IPM programs, which combine cultural, mechanical, biological, and chemical methods. Their role includes:

Releasing Trichogramma cards in rice, sugarcane, and cotton.

Spraying Bt formulations against caterpillars.

Introducing Cryptolaemus montrouzieri beetles to control mealybugs.

Conserving spiders and predatory mites by reducing pesticide use.

Conclusion

The use of natural enemies of major arthropod pests represents one of the most effective and sustainable approaches to pest management. Predators, parasitoids, and pathogens contribute significantly to reducing pest populations and form an essential component of modern Integrated Pest Management. While challenges such as mass production and farmer awareness persist, advancements in biological control technologies and increasing recognition of ecological farming systems are creating new opportunities. Strengthening extension services, farmer training, and supportive policies will further enhance the adoption of natural enemies in crop protection.

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Comparative Study of Sap-Sucking vs Chewing Insects

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Suraj Kumar Chaudhary

Student, School of Agriculture & Environmental Sciences, Shobhit Deemed University, Meerut (U.P.)

Insects are the most diverse and abundant group of organisms on Earth, with more than a million described species and several million more yet to be documented. They occupy virtually every ecological niche and play critical roles in agriculture, either as pollinators, decomposers, or herbivores. Among herbivorous insects, feeding strategies are diverse, ranging from external chewing to specialized sap-sucking. Two dominant feeding guilds in agriculture are sap-sucking insects and chewing insects, both of which are notorious for their destructive impact on crop plants.

Sap-suckers, including aphids, whiteflies, planthoppers, leafhoppers, and psyllids, belong largely to the order Hemiptera. They feed by inserting slender stylets into plant tissues to extract sap, typically from phloem or xylem. Their feeding often appears subtle, with little visible damage at first glance, but it induces chronic physiological stress and enables the spread of viral and phytoplasma diseases.

Chewing insects, on the other hand, include Lepidopteran larvae (such as *Spodoptera frugiperda* and *Helicoverpa armigera*), Orthopterans (grasshoppers and locusts), and Coleopterans (beetles). These insects possess heavily sclerotized mandibles designed for biting and tearing plant tissues. Their feeding causes acute and obvious destruction, ranging from leaf skeletonization to direct consumption of reproductive parts like flowers, pods, and fruits.

This comparative study explores the biology, ecology, damage mechanisms, and management strategies of sap-sucking versus chewing insects. It integrates case studies, ecological dimensions, and future prospects to highlight their importance in pest management research.

Literature Review

Research on insect feeding guilds has expanded significantly in the last century. Early entomologists, such as Wigglesworth (1939), provided fundamental insights into insect mouthpart morphology and feeding behavior. Later, studies by Painter (1951) emphasized host–plant resistance, highlighting the importance of insect–plant coevolution.

Recent molecular research has revealed the complexity of sap-sucking interactions. Aphid saliva contains effector proteins that modulate host defenses, suppressing salicylic acid signaling (Will et al., 2007). Studies on whiteflies (*Bemisia tabaci*) demonstrate their capacity to transmit over 100 plant viruses (Navas-Castillo et al., 2011).

Chewing insects have been extensively studied due to their devastating outbreaks. Fall armyworm (*Spodoptera frugiperda*), native to the Americas but recently invasive in Africa and Asia, has been the focus of genomic studies revealing rapid resistance evolution (Gouin et al., 2017). Helicoverpa armigera, another major chewing pest, shows remarkable adaptability and resistance to multiple insecticides, as documented in Sharma et al. (2005).

Despite extensive research, gaps remain in understanding how sap-sucking and chewing guilds interact with plant defense pathways differently, and how climate change might alter their outbreak dynamics.

Morphological and Physiological Adaptations

Sap-Sucking Insects

Possess piercing-sucking mouthparts: a proboscis containing maxillary and mandibular stylets. Specialized digestive system includes a filter chamber, which allows the rapid processing of dilute plant sap while concentrating nutrients. Depend on endosymbiotic bacteria (e.g., *Buchnera aphidicola*) for essential amino acids absent in plant sap. Small body size, short life cycles, and parthenogenesis (in aphids) enable rapid multiplication. Exhibit wing polymorphism (alate vs apterous forms), facilitating both sedentary feeding and dispersal.

Chewing insects

- Possess mandibulate mouthparts with heavily sclerotized mandibles.
- Salivary secretions contain proteases, amylases, and lipases, aiding in enzymatic digestion of solid plant tissues.
- Exhibit polyphagy: many lepidopteran larvae feed on dozens of host plants.
- Chewers display strong muscular development in the head capsule to support mandibles.
- Larger body size and higher food intake result in visible, large-scale plant damage.

Feeding Mechanisms

Sap-suckers

- Insert stylets intercellularly until they reach vascular tissues.
- Secrete watery and gelling saliva to lubricate stylets and suppress plant defenses.
- Feed for extended periods, continuously extracting sap.
- Excrete excess sugars as honeydew, which promotes secondary fungal growth (sooty mold).

Chewers

- Use mandibles to bite, tear, and macerate plant tissues.
- Cause direct removal of photosynthetic area, reducing productivity.
- Feeding is most destructive during larval stages.

- Trigger systemic wound responses in plants, activating jasmonic acid-mediated defenses and protease inhibitors.

Damage Symptoms and Economic Losses

Sap-suckers

- Leaf curling, chlorosis, stunting, and wilting.
- Transmission of plant viruses and phytoplasmas (e.g., rice tungro virus, cotton leaf curl virus).
- Hopper burn in rice due to massive brown planthopper infestations.
- Honeydew-induced sooty mold growth, reducing photosynthesis and contaminating fiber quality (in cotton).

Chewers

- Skeletonization of leaves, notches, and defoliation.
- Direct attack on flowers, pods, fruits, and seeds (e.g., pod borer in legumes).
- Stem boring and tunneling, weakening plants structurally.
- Locust swarms capable of devastating entire landscapes, threatening food security.
- Both guilds are capable of inflicting multi-billion-dollar economic losses annually.

Plant–Insect Interactions

Plants have evolved diverse strategies to resist insect attack.

Sap-sucker interactions: Plants produce secondary metabolites (alkaloids, phenolics) that reduce feeding. However, sap-feeders inject salivary effectors to suppress defense pathways. The salicylic acid pathway is often activated, but it may compromise jasmonic acid defenses against other pests.

Chewer interactions: Chewing damage induces jasmonic acid signaling, leading to production of defensive proteins such as proteinase inhibitors and polyphenol oxidases. Volatile organic compounds are released, attracting natural enemies of herbivores. Thus, sap-suckers manipulate plant defenses to their advantage, while chewers trigger stronger and more direct defensive responses.

Ecological and Evolutionary Dimensions

Sap-suckers reproduce rapidly and adapt quickly to resistant varieties. Their population explosions are favored by monocropping and excessive nitrogen fertilization.

Mutualisms: many sap-suckers (e.g., aphids) form relationships with ants, which protect them in exchange for honeydew.

Chewers such as armyworms and locusts exhibit migratory and gregarious behavior, enabling them to exploit large areas.

Climate change: rising temperatures accelerate insect development rates and expand their geographic ranges. Elevated CO_2 levels may increase sap-sucking pest fitness by altering plant nutritional quality. Both groups show rapid resistance evolution under pesticide pressure, albeit via different pathways: metabolic detoxification in chewers vs symbiont-mediated and behavioral resistance in sap-feeders.

Case Studies

Brown Planthopper (*Nilaparvata lugens*): Sap-sucker causing hopper burn in rice; notorious for repeated outbreaks in Asia.

Cotton Whitefly (*Bemisia tabaci*): Transmits cotton leaf curl virus and other plant viruses.

Cotton Aphid (*Aphis gossypii*): Sap-sucker that reduces lint quality by honeydew contamination.

Fall Armyworm (*Spodoptera frugiperda*): A chewing pest of maize, invasive in Africa and Asia; causes up to 50% yield losses.

Helicoverpa armigera: Pod borer of pulses, tomato, and cotton; polyphagous and highly resistant to insecticides.

Desert Locust (*Schistocerca gregaria*): Migratory chewer capable of consuming its own body weight in vegetation daily, leading to regional famines.

Pest Management Strategies

Conventional

Sap-suckers: controlled by systemic insecticides such as neonicotinoids (imidacloprid, thiamethoxam).

Chewers: managed with contact insecticides including pyrethroids and organophosphates.

Biological

Natural enemies like coccinellids (ladybird beetles), syrphid flies, and parasitoid wasps control sap-suckers. Parasitoids such as *Trichogramma* and predators like birds and spiders regulate chewing insects.

Cultural

- Crop rotation, trap crops, and resistant varieties reduce pest buildup.
- Intercropping suppresses population growth of both guilds.

Biotechnological

- Bt crops (cotton, maize) highly effective against chewing insects but less so for sap-feeders.
- Emerging technologies: RNA interference (RNAi) and CRISPR gene editing hold promise for both sap-suckers and chewers.

Integrated Pest Management (IPM)

- Combines monitoring, threshold-based spraying, biological control, and cultural methods.
- Emphasizes sustainability and reduced reliance on chemicals.

Future Prospects & Research Gaps

- Need for climate-smart pest management frameworks.
- Exploitation of endosymbionts in sap-suckers as novel control targets.
- Development of multi-gene resistant crops combining Bt toxins with RNAi constructs.
- Predictive modeling of outbreaks using remote sensing and AI.
- Greater focus on ecological engineering to conserve natural enemies.

Conclusion

Sap-sucking and chewing insects represent two contrasting but equally destructive feeding guilds in agriculture. While sap-suckers exploit vascular tissues and serve as efficient vectors of plant pathogens, chewers cause direct tissue destruction and rapid yield losses. Their differences in morphology, physiology, feeding, and ecology demand distinct management approaches. However, both groups share the ability to adapt rapidly, evolve resistance, and exploit human agricultural practices.

Sustainable management will depend on integrating modern biotechnology with ecological approaches, minimizing pesticide dependence, and strengthening natural pest regulation. Understanding their comparative biology is not only crucial for immediate crop protection but also for future food security under changing climatic conditions.

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Impact of Training and Extension Services on Horticulture Development

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Dinesh Kumar Meena

Department of Horticulture, School of Agricultural Sciences and Technology, Babasaheb Bhimrao Ambedkar University (A Central University), Vidya Vihar, Raebareli Road, Lucknow-226025, (UP.)- India.

Horticulture-including fruits, vegetables, flowers, ornamentals and nursery crops-has become a vital pillar of agricultural growth, nutrition and livelihood diversification. However, to realize its full potential, producers need access to updated scientific knowledge, improved techniques, and market linkages. That is where training and extension services come into play. They bridge the gap between research-lab developments and field adoption. This article examines how training and extension services influence horticultural development, what factors affect their effectiveness, challenges and suggestions for improvement.

Role of Training and Extension Services

Knowledge and Skill Transfer

Extension services-through demonstration plots, farmer field schools, workshops and on-farm training-help farmers understand best practices in planting, pest and disease control, soil health, post-harvest handling, pruning and varietal selection. Training furthers human resource development among extension staff themselves, ensuring they are capable of delivering modern, relevant information. In Punjab, for example, trained horticultural extension workers from Punjab Agricultural University help motivate farmers to adopt horticulture as entrepreneurial activity.

Technology Adoption

Without training, farmers may not adopt innovations such as improved varieties, integrated pest management (IPM), drip irrigation, shade net / polyhouse technologies or post-harvest technologies. Extension agents act as change agents, allowing these technologies to diffuse. In India, the National Horticulture Mission (NHM) beneficiaries had contact with extension personnel (agricultural assistant, assistant agriculture officer etc.), which correlates with their participation in extension programmes like training, field visits etc.

Improved Productivity, Quality and Income

Better practices reduce losses (especially post-harvest), improve yields and enhance quality (appearance, shelf life). For example, the Transfer of Technology (ToT) programmes of NHRDF (National Horticultural Research and Development Foundation) have resulted in increased productivity and area under horticultural crops by educating farmers using demonstrations, field days etc.

Market Access and Value Chains

Extension services often include training on grading, packing, market norms, negotiation collective marketing, etc., enabling producers to get better prices and access higher value markets. Improved quality through training (post-harvest handling, cleanliness and packaging) allows horticultural produce to meet market / export standards.

Sustainability and Resilience

Training plays a part in disseminating sustainable practices: organic farming, water-conserving methods, integrated pest management, soil-fertility management. Extension can also help farmers adapt to climate change by providing new climate-smart practices, resilient varieties, etc. For example, extension in organic farming helps increase awareness of pest management, soil health, shift to organic practices.

Empirical Evidence / Case Studies

National Horticulture Mission (Karnataka, India)

A study on NHM beneficiaries in found that sources of information for farmers include family, media, internet, etc. They also found that only about 28.5% of beneficiaries were participating in training programmes, 31% in field visits, ~33% in group meetings / Krishi melas (farmers' fairs). This suggests that while extension contact is present, training reach and participation are lower than optimal.

Horticultural Extension and Training in Punjab, India

In Punjab, data indicates that training and extension education programs (by PAU, KVKs etc.) have played a role in diversifying cropping patterns, raising awareness among farmers, women, and youth, and improving adoption of horticultural crops.

Training Needs of Horticulture Extension Personnel in Jammu & Kashmir

A study in J&K among horticulture extension personnel (HDOs: Horticulture Development Officers; technicians) found that education level, information use are strongly associated with knowledge. Key training areas perceived: insect/pest identification and control, variety identification, nursery management, pruning. Constraints included inadequate staff, facilities, and inconsistent job promotion.

Projects using ICT and Mobile Advisory Services

In India, Nepal, Sri Lanka, pilot projects using cell phone based advisory services (voice, text and photo) have been tried for horticultural crop growers in greenhouses/ shade nets. These aim to deliver real-time, personalized advice. Such approaches, combined with training, help expand reach.

Factors Affecting Effectiveness

Effectiveness of training and extension depends on:

- **Frequency and Quality of Contact**: Regular extension contacts, follow-ups and sustained support (hand-holding) are more effective than sporadic training.

- **Relevance and Localization**: Training content must match local agro-ecological conditions, crop types, pest/disease pressures and socio-economic conditions.
- **Capacity of Extension Personnel**: Their own training, knowledge, communication skills, competence affect how well they can train farmers. The study in Jammu & Kashmir emphasized that extension personnel valued technical and communication training.
- **Infrastructure and Resources**: Existence of demonstration plots, field days, transportation, communication media and cold storage etc. Without these, knowledge may not translate into practice.
- **Incentives and Institutional Support**: Government policies, funding, institutional frameworks (e.g. Krishi Vigyan Kendras, ATMA and public private partnerships) that support extension strongly.
- **Behavioural, Cultural and Social Barriers**: Farmer risk aversion, traditions, gender norms, literacy level and trust in extension agents etc.

Challenges

- **Low Participation**: Many farmers do not attend training due to cost, distance, time constraints. In the NHM study in Karnataka, training participation was only ~28.5% among beneficiaries.
- **Inadequate Scale and Reach**: Extension agents often have large areas and many farmers to cover; resource constraints limit reach.
- **Mismatch between Research & Field Reality**: Sometimes technologies developed in research stations may not be adaptive to local contexts (climate, soil and markets).
- **Insufficient Follow-Up / Hand Holding**: Training is often one-off; without follow-ups or support, adoption may drop.
- **Lack of Market Infrastructure and Value Chains**: Even if farmers produce well, if market linkages, packaging, storage are weak, profits may not accrue.
- **Limited Use of ICT and Modern Communication**: While efforts exist (mobile advisory and SMS etc.), digital literacy, network issues, cost etc. remain bottlenecks.

Diagram: Model of Training and Extension Service Flow in Horticulture

Here is a suggested diagram (you can imagine or sketch) of how training and extension services interact in horticultural development:

│ Research Institutes │
│ (Varieties, Pest, Fertility, Post-Harvest etc.) │

│ Transfer of technology & best practices │
▼

│ Extension Agencies / KVKs / NGOs / Govt Departments │
│ & Extension Personnel │

│ │

Training of extension staff │

(skills, technical, communication)

│ │

▼ ▼

Training of farmers / grower groups / farm women etc.

Field demonstrations │ Workshops, Field Days

Advisory services │ Mobile / ICT / Phone / SMS

│ │

▼ ▼

Adoption of improved technologies, sustainable practices

Better pest/disease control, improved quality & yield

│

▼

Market / Value chain (quality, packaging and transport)

│

▼

Improved income, nutrition and livelihoods

▲

│ Feedback │

Impacts / Outcomes

From literature and projects, observed impacts include:

- **Increased Productivity and Area under Horticultural Crops**: Training and extension have led farmers to diversify their cropping into high-value fruit/vegetable/flower crops. E.g. Punjab had low area under horticulture; extension education is aiding diversification.
- **Improved Quality and Reduced Losses**: Better post-harvest handling (sorting, packing), disease/pest control reduce losses, improve shelf-life.
- **Enhanced Income and Livelihoods**: With better yields, quality, market linkage, incomes rise. Training helps farmers access markets.
- **Adoption of Sustainable Practices**: Organic methods, water-efficient irrigation, integrated pest management promoted via extension reduce input cost and environmental impact.
- **Empowerment and Capacity Building**: Particularly for women, youth, marginalized farmers: through training they gain skills, confidence and better decision making.

Policy Implications & Suggestions

To maximize impact, some policy and operational suggestions:

1. **Strengthen Extension Institutions**: Increase number of extension staff, improve their training, supervision and ensure accountability.
2. **Demand-Driven Extension**: Tailor extension to what farmers want / need; involve them in planning.
3. **Use of ICT / Digital Platforms**: Scale up mobile advisory, SMS, apps and social media, video demonstrations. Ensures timely advice and wider reach.
4. **Focus on Post-Harvest, Market Linkages, Value Addition**: Training must include value chain components, not just production.
5. **Continuous Follow-Up / Monitoring & Evaluation**: Do not assume training ends with

workshop. Need follow-ups for adoption, measure impact and refine content.

6. **Inclusive Extension**: Special attention to smallholders, women, youth and marginalized groups. Ensure accessibility (time, location and cost).
7. **Public-Private Partnerships (PPP)** and Farmer Producer Organisations (FPOs) can help in scaling, outreach and resource mobilization.

Conclusion

Training and extension services are foundational to horticulture development. They facilitate technology adoption, improve productivity and quality, enhance income and support sustainable practices. However, their effectiveness depends heavily on quality, relevance, fit to local conditions and strong institutional support. To fully harness horticulture's potential for food security, livelihoods and economic growth, concerted efforts are needed to strengthen and modernize extension systems, especially in developing countries like India.

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Host Plants and Impact of Thrips (Thysanoptera)

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Vinit

Student, School of Agriculture & Environmental Sciences, Shobhit Deemed University, Meerut (U.P.)

Thrips (*Thysanoptera*) are minute, fringed-wing insects that have emerged as pests of global agricultural importance. Their damage arises not only from direct feeding but also from their efficiency as vectors of plant-infecting tospoviruses. Thrips infest a vast range of host plants, spanning vegetables, fruits, ornamentals, field crops, and weeds, thereby complicating management. Their cryptic habits, high reproductive rate, and ability to develop resistance to insecticides make them especially problematic. This article reviews the host associations of economically important thrips species, their direct and indirect impacts on crop productivity and quality, and the broader ecological and economic implications of their pest status.

Thrips are among the smallest phytophagous insects but exert disproportionately large economic impacts. Belonging to the order *Thysanoptera*, they include more than 6,000 species, of which approximately 1% are considered crop pests (Mound, 2005). Thrips possess asymmetrical piercing–sucking mouthparts, uniquely adapted for scraping epidermal cells and sucking out contents. Their feeding produces characteristic silvering, scarring, and deformation of plant tissues.

Thrips are not only polyphagous feeders but also vectors of tospoviruses, such as *Tomato spotted wilt virus* (TSWV), *Impatiens necrotic spot virus* (INSV), and *Groundnut bud necrosis virus* (GBNV), which can decimate yields. Because tospovirus transmission is persistent and propagative, the virus replicates inside the thrips, making control extremely difficult (Ullman et al., 1997).

Taxonomic Overview of Thrips

Order: Thysanoptera

Families: Phlaeothripidae and Thripidae (the latter includes most crop pests).

Key Pest Genera: *Thrips*, *Frankliniella*, *Scirtothrips*, *Caliothrips*.

Notable Pest Species:

- *Thrips tabaci* (onion thrips)

- *Frankliniella occidentalis* (western flower thrips)
- *Thrips palmi* (melon thrips)
- *Scirtothrips dorsalis* (chilli/mango thrips)
- *Frankliniella schultzei* (common blossom thrips)

Host Plants of Thrips

Vegetables

- *Thrips tabaci*: Onion, garlic, leek, cabbage, tomato, potato.
- *Thrips palmi*: Eggplant, chilli, cucumber, pumpkin, watermelon, gourds.
- *Frankliniella occidentalis*: Tomato, pepper, lettuce, beans, spinach, greenhouse vegetables.

Field Crops

- Cotton: leaf curling, stunting at the seedling stage.
- Groundnut: bud necrosis (via GBNV).
- Soybean: flower abortion, reduced pod set.
- Sunflower, maize, wheat (sporadic infestations).

Fruit Crops

- *Scirtothrips dorsalis*: Mango (inflorescence damage), grapes (bronzing), strawberry (fruit scarring), citrus.
- *F. occidentalis*: Strawberry, grape, kiwi.
- *Caliothrips indicus*: Citrus thrips in India.

Ornamentals

- Roses, chrysanthemum, gerbera, gladiolus, carnation, tulip, orchid.
- Damage: petal streaking, flower deformation, discoloration — major quality loss.

Weeds as Reservoirs

- *Amaranthus*, *Parthenium hysterophorus*, *and Solanum nigrum* serve as virus reservoirs and thrips breeding hosts.
- Presence of weeds correlates with outbreak intensity in nearby crops (Kirk & Terry, 2003).

Impacts of Thrips

Direct Impacts

1. **Feeding Injury**

- Leaves: silvery streaks, necrosis, curling, stunting.
- Flowers: petal distortion, premature senescence, reduced pollination.
- Fruits: bronzing, corky scars, pitting, and downgrading of quality.

2. **Growth Reduction**

- Severe seedling attack leads to poor establishment (onion, cotton, chilli).
- Continuous feeding reduces photosynthesis and vigor.

3. **Marketability Issues**

- Ornamentals: even slight petal damage leads to rejection.
- Fruits/vegetables: scarring reduces grade and export potential.

Indirect Impacts

1. **Virus Transmission**

- Over 20 tospoviruses are transmitted by thrips.

Examples:

- *Thrips tabaci* → Iris yellow spot virus (IYSV) in onion.
- *F. occidentalis* → TSWV, INSV in vegetables/ornamentals.
- *T. palmi* → Peanut bud necrosis virus (PBNV).
- *S. dorsalis* → Capsicum chlorosis virus (CaCV).
- Viral diseases often result in yield losses exceeding 50–80%.

2. **Quarantine Significance**

- Infestation leads to export rejection (cut flowers, strawberries, capsicum).
- Western flower thrips is considered a quarantine pest in many countries.

3. Resistance Development

- Thrips rapidly develop resistance to pyrethroids, organophosphates, carbamates, and even some newer chemistries (Reitz, 2009).
- Resistance complicates pest management, escalating costs.

Case Studies of Economic Loss

- **Onion (India):** IYSV transmitted by *T. tabaci* has reduced bulb yields up to 60%.
- **Groundnut (South Asia):** PBNV vectored by *T. palmi* has caused yield losses of 30–70%.
- **Tomato (USA & Europe):** TSWV epidemics in tomatoes and peppers due to *F. occidentalis* infestations, necessitating costly IPM programs.
- **Strawberry (California, Spain):** Fruit bronzing and downgrading caused by *F. occidentalis* infestations.

Ecological and Evolutionary Implications

- Thrips thrive in warm, dry climates, with populations exploding in drought conditions.
- Their polyphagy and short generation time allow adaptation to diverse hosts.
- Virus-vector interactions are evolutionary drivers — tospoviruses enhance thrips survival and reproduction, creating a mutualistic relationship (Ullman et al., 1997).

Conclusion

The impacts of thrips are multifaceted: direct feeding reduces photosynthetic efficiency and aesthetic quality, while virus transmission causes catastrophic yield losses. Their wide host range ensures continuous survival, and resistance evolution challenges conventional control. The persistence of thrips across vegetables, field crops, fruits, and ornamentals underscores the need for holistic management, combining cultural sanitation, biological control (predatory mites, *Orius* spp.), and rational chemical use.

8. Conclusion

Thrips represent a significant constraint to sustainable crop production worldwide. Their ability to colonize multiple host plants, cause direct tissue damage, and transmit devastating viruses makes them one of the most challenging pest groups to manage. Future strategies should prioritize IPM, resistance monitoring, and exploitation of natural enemies, alongside strict quarantine enforcement to prevent global spread.

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Mango: The Golden Fruit of Nutrition and Wellness

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Garima Dixit[2], Sadhna Singh [1], Sheetanu Singh,[2], Priya Pandey[2]

[1]Professor, Department of Food and Nutrition, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya

[2]Research Scholar, Department of Biochemistry, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya

Mango (*Mangifera indica* L.), a member of the Anacardiaceae family, is widely revered in tropical regions and is often dubbed "the king of fruits." Originating from the Indian subcontinent, mango has seen historical cultivation since the 5th–4th centuries BCE in Southeast Asia, followed by its spread to East and West Africa by the 10th century CE, and later to regions such as Brazil, Mexico, Spain, the Canary Islands, Portugal, the Caribbean, and the West Indies. Today, countries like India, China, Thailand, and Mexico lead in global mango production and exportation.

The mango tree is a fast-growing, evergreen orchard species with a robust canopy and glossy, pointed leaves. It flourishes in tropical climates, reaching heights of 30–40 meters, though growth is slower in subtropical areas. The tree produces large panicles of up to 3,000 small whitish-red or yellow-green flowers. Mango fruits vary extensively in taste, size, and shape across hundreds of cultivars, typically measuring 5–15 cm in length and weighing between 150–750 g. In Sicily, the average fruit weight is around 390 g. Nutritionally, mangoes offer approximately 15% carbohydrates, 1.6% dietary fiber, 0.38% fat, and 0.82% protein—making them a valuable addition to a balanced diet.

Health Benefits of Mango

1. **Polyphenol Powerhouse:** Mangoes are abundant in health-promoting polyphenols such as gallic acid and gallotannins, known for their therapeutic properties.
2. **Antioxidant Defense:** These polyphenols help counteract oxidative stress by neutralizing harmful free radicals, protecting cellular structures from damage.

3. **Anti-inflammatory and Anticancer Potential:** Mango's bioactive compounds help combat inflammation and may offer protective effects against chronic gastrointestinal disorders and colon cancer.
4. **Supports Gut Integrity:** Regular mango intake may reduce inflammation in the intestines, strengthen the gut lining, and alleviate symptoms of constipation and leaky gut.
5. **Natural Prebiotic:** Both mango polyphenols and its dietary fiber act as prebiotics, encouraging the proliferation of beneficial gut bacteria.
6. **Microbiota Synergy:** The health effects of gallotannins are significantly influenced by their metabolism through gut microbiota, highlighting their microbiome-dependent benefits.
7. **Colon Health Protection:** Mango intake may help modulate pro-inflammatory cytokines involved in colon diseases, potentially lowering cancer risk.
8. **Safe Enzyme Interaction:** While interaction with digestive and hepatic enzymes is theoretically possible, such effects are negligible at normal dietary levels.
9. **Gut–Brain Axis Influence:** Recent research has indicated that mango polyphenols may affect cognitive functions through their action on the gut–brain axis.

Functional Mango Recipes

1. Mango Probiotic Smoothie

Gut-friendly and refreshing.

Ingredients:

- 1 cup ripe mango pulp
- 1 cup probiotic yogurt
- 1 tbsp honey (optional)
- 1 tsp chia seeds

Method: Blend all ingredients until smooth. Serve cold.

2. Mango-Oat Breakfast Bowl

Promotes digestion and keeps you full.

Ingredients:

- ½ cup soaked rolled oats
- ½ cup diced ripe mango
- ½ banana
- 1 tbsp flaxseeds
- ½ cup dairy or plant-based milk

Method: Combine ingredients and serve chilled.

3. Mango Chia Pudding

Rich in fiber and supports gut-brain health.

Ingredients:

- 1 cup mango puree
- 3 tbsp chia seeds
- 1 cup coconut milk
- 1 tsp vanilla extract

Method: Mix well and refrigerate overnight. Garnish with fresh mango.

Who Should Avoid or Limit Mango Intake?

While mango offers numerous health benefits, some individuals should consume it with caution:

- **People with Diabetes**: Due to its high natural sugar content, mango can elevate blood glucose levels. Diabetics should monitor portions.
- **Latex Allergy Sufferers**: Mango peel contains compounds similar to those in latex, potentially triggering allergic responses in sensitive individuals.

- **Individuals with IBS or Fructose Sensitivity**: Mangoes contain fermentable sugars (FODMAPs) that may cause bloating or gastrointestinal discomfort in people with irritable bowel syndrome.
- **Those Prone to Kidney Stones**: Mango contains moderate amounts of oxalates, which can contribute to stone formation in susceptible individuals when eaten in excess.

Facts About Mangoes

- There are over 1,000 varieties of mangoes worldwide.
- The world's heaviest mango weighed over 4.25 kg (9.36 lbs)
- Mango leaves are used in Hindu religious ceremonies.
- Mango peels are edible and rich in nutrients.
- Mangoes belong to the same plant family as poison ivy.
- A single mango tree can live for more than 100 years

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The Residues of Turmeric and Ginger: Uses, Benefits, and Management

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Ritik Kumar

Student, School of Agriculture & Environmental Sciences, Shobhit Deemed University, Meerut (U.P.)

Turmeric (Curcuma longa L.) and ginger (Zingiber officinale Rosc.), belonging to the family Zingiberaceae, are among the most economically and medicinally valuable spice crops cultivated worldwide. India remains the leading producer of both crops, where they are used extensively for culinary, pharmaceutical, and industrial purposes (El-Saadony et al., 2023).

The processing and consumption of turmeric and ginger generate substantial residues in the form of peels, fibrous waste, pulp, and spent materials. While often treated as agricultural waste, these residues are rich in bioactive compounds such as polyphenols, fibers, and essential oils, making them valuable for medicine, agriculture, food, and industry (Monteiro et al., 2023). This article discusses the nature of these residues, their chemical composition, and their sustainable utilization, with insights from recent studies.

Types of Residues in Turmeric and Ginger

Residues are produced at different stages of production and use:

1. Harvest Residues

Turmeric: rhizome peel, undersized rhizomes, and rootlets.

Ginger: outer peel, fibrous tissues, and non-marketable rhizomes.

2. Processing Residues

Turmeric: polishing waste, powder dust, and spent turmeric after curcumin extraction.

Ginger: pulp and fibrous residues after oleoresin or oil extraction (Spyrou et al., 2024).

Consumption Residues

Kitchen waste such as peels, leftover powders, and juice press-cakes.

Nutritional and Chemical Composition

Research shows that turmeric and ginger residues retain significant levels of bioactive and nutritional compounds:

- Turmeric Residues contain residual curcumin, starch, essential oils, and dietary fibers, all contributing to antioxidant and antimicrobial activities (El-Saadony et al., 2023).
- Ginger Residues are rich in gingerols, shogaols, phenolic compounds, and fibers, which possess antioxidant, anti-inflammatory, and antimicrobial properties (Gulzar et al., 2023).
- Studies by Tinello and Lante (2019) demonstrated that turmeric and ginger peels exhibit stronger antioxidant activities compared to commercial powders, suggesting high potential in nutraceutical applications.

Applications of Turmeric and Ginger Residues

1. Medicinal and Pharmaceutical Uses

Residues contain phenolics and oils that support the development of herbal medicines. Ginger waste, for instance, retains gingerols effective in anti-nausea formulations, while turmeric residues have residual curcumin beneficial in wound healing and anti-inflammatory products (Zhang et al., 2025).

2. Food Industry Applications

Residues are increasingly used in functional foods. Ginger pulp and turmeric starch enhance flavor, fiber content, and shelf life. Sedyadi et al. (2019) reported that incorporating ginger and turmeric extracts into edible packaging films extended tomato shelf life up to 65 and 60 days, respectively, by reducing shrinkage and preserving texture.

3. Agricultural Applications

Residues act as organic manure and enhance soil fertility when composted. Extracts from turmeric residues also serve as natural pest repellents against storage insects (Tinello & Lante, 2019). Ginger residues are sometimes incorporated into livestock feed, improving digestion and growth performance (Gulzar et al., 2023).

4. Industrial Applications

Both turmeric and ginger residues have significant industrial value.

- Turmeric residues are used as natural dyes in textile industries (El-Saadony et al., 2023).
- Ginger residues are utilized for biofuel production, including bioethanol and biogas, through fermentation processes (Spyrou et al., 2024).
- Residues are also being explored for biodegradable packaging materials, supporting eco-friendly innovations (Monteiro et al., 2023).

Environmental Significance

Proper utilization of turmeric and ginger residues reduces waste accumulation and environmental pollution. Instead of contributing to landfills and greenhouse gas emissions, residues can be integrated into a circular bioeconomy, where waste is converted into high-value products (Monteiro et al., 2023).

Challenges in Residue Utilization

Despite their potential, challenges remain:

- Lack of awareness among small-scale farmers and processors.
- Absence of cost-effective extraction technologies.
- High moisture content, leading to microbial spoilage if not processed quickly (Spyrou et al., 2024).

Future Prospects

Research suggests promising future directions:

- Development of eco-friendly extraction methods for recovering bioactive compounds (Spyrou et al., 2024).
- Use of residues in active food packaging to extend shelf life naturally (Sedyadi et al., 2019).
- Expansion of biorefinery models, where every component of turmeric and ginger residues is valorized for food, pharmaceuticals, and industry (Monteiro et al., 2023).

Conclusion

Turmeric and ginger residues, often neglected as waste, represent significant opportunities for value addition. With proven roles in medicine, food, agriculture, and industry, their sustainable management contributes to both economic development and environmental protection. Harnessing these residues through advanced processing technologies and residue-based value chains will strengthen their role in a sustainable circular bioeconomy.

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Grafting in Vegetables: A Novel Technology to Augment Sustainable Vegetable Production

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Ashish Kumar Brahma[1], Barsha Tripathy[1] and Ananya Mishra[2*]

[1]Department of Vegetable Science, Faculty of Agricultural Sciences, Siksha O Anusandhan Deemed to be University, Bhubaneswar 751003, Odisha, India

[2]Department of Vegetable Science, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar-751003, Odisha, India

Grafting is a technique typically employed in vegetable crops to increase yield and profitability, improve resistance to biotic stresses and tolerance to abiotic stresses. Grafting is a technique in which a scion (the above-ground part, chosen for desirable fruit traits) is joined onto a rootstock (chosen for its vigour, stress or disease tolerance) so that the two grow as one plant. In order to prevent *Fusarium* wilt, watermelon (*Citrullus lanatus* L.) plants were grafted onto bottle gourd (*Lagenaria siceraria* L.) in Japan in the late 1920s, marking the first documented usage of vegetable grafting (Kawaide, 1985). Grafting has been used all over the world since then. Grafted seedlings are used in watermelon-growing areas in Japan and Korea. Grafting can be a useful technique to handle a variety of abiotic challenges including drought, heat, heavy metal toxicity, salinity and nutrient deficiencies or toxicity, in addition to reducing biotic stress from root-knot nematodes and soilborne fungus. Grafting is mostly utilized in protected horticulture to increase vegetable crop yield and resource efficiency. Establishing appropriate grafting techniques and robust rootstock development through breeding are prerequisites for the adoption of grafting.Even though grafted seedlings have advantages, not all vegetable species can be grafted since grafting success depends on a variety of criteria, including genetic background, growth characteristics, anatomy and physiological and biochemical aspects. Solanaceae family in general (Tomato and Brinjal in particular) and Cucurbitaceae family in general (Watermelon, Melon and Cucumber in particular) are among the vegetable crops that are frequently and profitably grafted.

Purpose of Vegetable Grafting

Vegetable grafting serves several goals, including increasing plant vigour, influencing sex expression (Mibus *et al.,* 2000), developing resistance to soil-borne diseases and pests, improving yield and quality traits and gaining tolerance to abiotic stresses. These goals can all help reduce the need for fertilizers and agrochemicals (Lucas *et al.,* 2017).

Important Pre-requisites for Transplanting Vegetables Grafts

Choosing The Appropriate Scion or Rootstock: Choose a scion with the same diameter as the desired rootstock. The ideal time to graft is between two and three genuine leaf stages.

Graft Compatibility: Even at later stages of growth, a compatible rootstock and scion reduce the mortality rate. Vascular bundles are formed as a result of the quick callus formation that occurs between the scion and rootstock.

Grafting Tools: Grafting blades, tubes, pins, and clips are often used tools for grafting.

Screening House: Before grafting, seedlings are grown in a screening house. 60-mesh nylon net should be used in its construction. To stop UV radiation from penetrating, place a separate UV-resistant polyethylene covering over the upper half of the structure and arrange a double door.

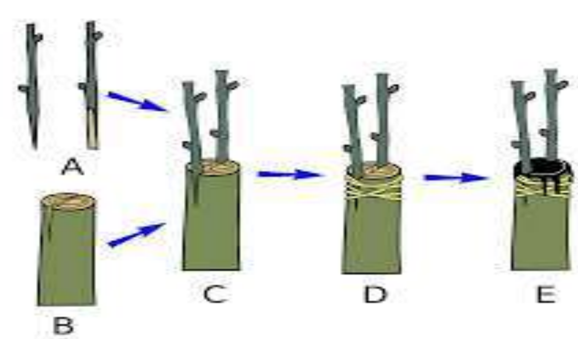
Healing Of Grafts: Graft healing is essential for creating the ideal environment for grafted seedlings to develop calluses. To encourage callus formation at the union, the healing chamber should be kept at 28 to 29˚C with 95% relative humidity for five to seven days in a slightly shaded area (dark for one to two days). By lowering transpiration, maintaining high humidity, maintaining the ideal temperature and reducing light intensity, it aids in the creation of better graft union. The primary goal is to establish a suitable environment by regulating humidity and temperature.

Acclimatization of The Grafted Plants: To avoid leaf burning and wilting, plants may be placed under a clear plastic cover or greenhouse or mist chamber once the callus has developed and the injured areas have healed.

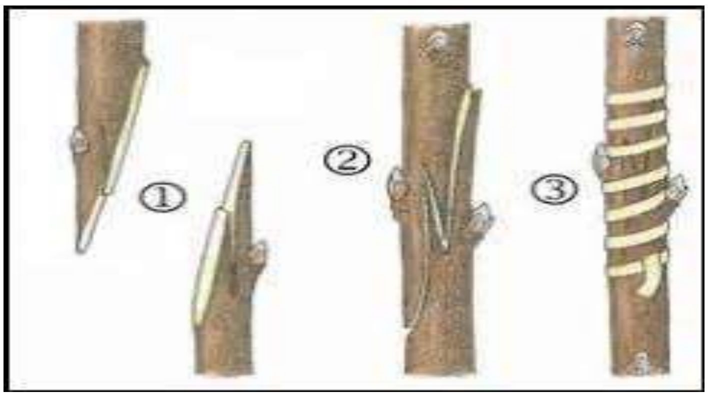
Different Grafting Methods used in Vegetable Grafting

The crop, the farmer's expertise, personal preference, the quantity of grafts needed, the goal of grafting, labour availability and the availability of infrastructure and machinery all influence the choice of grafting technique. The most common and extensively utilized technique is hand grafting, despite the development of numerous machines and grafting robots.

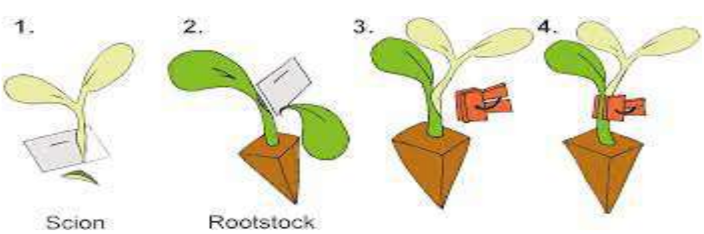
(a)Cleft Grafting: Another name for it is wedge grafting or apical grafting. Here, scion plants with one to three true leaves are clipped, and the lower stem is trimmed at an angle to create a tapered wedge. After the scion is placed into the split, a clip is inserted to allow the scion and rootstock to come into contact (Johnson *et al.,* 2011). The most common usage of this technique is in solanaceous crops.



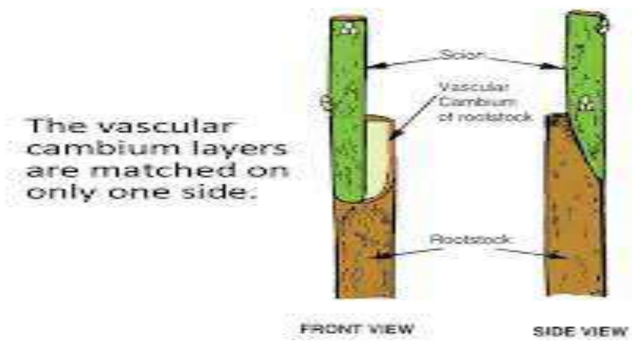
(b) Tongue/Approach Grafting: For this grafting, the rootstock and scion materials are of equal size. Therefore, scion seeds are placed five to seven days before rootstock seeds in order to achieve a consistent size. Farmers and small nurseries utilize this approach the most since it is labour-intensive and takes up more room, but the seedling survival rate is good. Rootstocks with hollow hypocotyls are not suitable for this technique.



(c) Hole Insertion/Top Insertion Grafting: This is the most widely used technique for cucurbits, and it prefers rootstock with hollow hypocotyls. Because watermelon seedlings are smaller than bottle gourd or squash rootstock, this technique is recommended for producing grafted watermelon seedlings. Up until transplanting, this technique requires an ideal temperature of 21–36˚C. Compared to the tongue grafting technique, this procedure yields a stronger union and vascular connection, which is why it is so widely used in China.



(d) Splice Grafting/ Tube Grafting / One Cotyledon Splice Grafting: Commercially graded transplant producers and growers are the ones who employ this technique the most. It can be done manually or with machinery on the majority of vegetables. Cucurbits and other solanaceous vegetable crops are commonly grown using this technique.



(e) Pin Grafting: Splice grafting and pin grafting are comparable. To maintain the grafted position, specifically made pins are utilized in place of grafting clips.

Figure 6: Pin grafting position specially designed pins are used

To achieve a higher success rate for the grafting procedure, newly grafted grafts must be properly cared for. In order to prevent (95%) water loss, humidity should be maintained. If the scion loses water during the first two days, it may wilt, and the grafting operation may fail. To improve humidity, reduce light intensity, and accelerate the healing process, grafted transplants should be covered with black plastic sheeting for five to seven days following grafting.

Table 1: Recommended techniques of grafting and rootstocks in vegetable crops

Plant (Scion)	Grafting Technique	Rootstock
Watermelon	Slice grafting, cleft technique and top insertion	*Lagenaria siceraria, Cucurbita moschata, Cucurbita melo, Cucurbita moschata × Cucurbita maxima, Benincasa hispida*
Cucumber	Top insertion and Tongue grafting	*Cucurbita maxima, Cucurbita moschata*
Bottle gourd	Top insertion and Tongue grafting	*Luffa sp., Cucurbita moschata*
Bitter gourd	Top insertion and Tongue grafting	*Lagenaria siceraria, Cucurbita moschata*
Brinjal	Tongue and Cleft grafting	*Solanum khasianum, Solanum sisymbriifolium, Solanum torvum*
Tomato	Tongue and Cleft grafting	*Solanum nigrum,* *Solanum lycopersicon,* *Solanum pimpinellifolium*

Survival Rate and Compatibility with Grafts

The quality of fruit borne on the scion is influenced by rootstocks for a variety of reasons. The most evident is rootstock/scion incompatibility, which causes the scion to grow either excessively or insufficiently, thereby reducing the flow of nutrients and water through the grafted union and ultimately resulting in wilting. However, rootstock/scion pairings should be carefully chosen for specific climatic and geographic conditions to achieve a positive influence of grafting on vegetable quality. Grafted plants utilizing *Solanum torvum* rootstock had the highest survival rate.

Issues Encountered during Transplanting of Grafted Vegetables

The following are some issues related to the creation and administration of grafted transplants:

- This method is labour-intensive and calls for people with particular training.
- Needs time management for the sowing of scion and rootstock seeds.
- Need a regulated setting in order to heal grafts.
- Grafting may make it more likely for diseases to spread, particularly those that are seed-borne in the nursery.
- Grafting workers in greenhouses and growth chambers frequently experience discomfort and heat stress, particularly in April, June, September and October (Marucci *et al.,* 2012).

Current Status of Vegetable Grafting

Due to the significant concentration of cucurbits and other grafted vegetables, East Asia is the largest market for vegetable grafting. Grafted transplants are used to produce 90%, 94%, and 40% of watermelon in China, Japan and Korea, respectively (Bie *et al.,* 2017). Grafted transplants are used to generate roughly 60–

65% of tomatoes and brinjal and 10%-14% of peppers, which are considered solanaceous vegetables. Grafted tomato transplants are used for all tomatoes grown in the Netherlands without soil. Vegetable grafting is gaining popularity worldwide, particularly in India, the Philippines, North America, South America, and Eastern Europe. Grafted transplants are being produced in more than 1500 commercial nurseries in China. Grafted vegetable transplants are becoming increasingly traded internationally, as evidenced by Canada's shipments of grafted transplants to Mexico (Bie *et al.,* 2017).

Conclusion

Grafting is a green technology that encourages the production of organic vegetables. The management and production of nurseries require a lot of labour. To improve grafting efficiency and reduce labour costs, scientists must focus on developing and promoting facilities, tool and grafting robots. Researchers must consider grafted transplant storage technologies. The creation of databases, software, mobile applications and crop models related to grafted vegetables will help farming communities and nursery managers select the best scion and rootstock cultivars. The grafted transplant trade is growing rapidly on the global market and as the grafted vegetable industry in India develops, this option can be utilised to generate foreign exchange. This technology can positively contribute to crop output. Improvements have been made to increase the technique's adoption, such as the development of more efficient grafting robots that can complete numerous tasks quickly and reduce the cost of grafted seedlings. Another breakthrough is the creation of rootstocks that offer a strong root system, resistance to diseases carried by the soil, the ability to promote greater shoot vigour by increasing nutrition and water absorption and preservation of plant health, all of which would boost output. Vegetable grafting offers a promising and practical way to combine the best traits of two plants, high fruit quality from the scion and resilience from the rootstock, enhancing productivity and sustainability. But it demands careful choice of combinations, proper technique and controlled healing conditions to succeed.

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Seeds in Safe Hands: The Rise of Biodegradable Antifungal Coatings

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Karan Singh Jatt

Lovely Professional University ,Punjab -144411

Internal Hidden Battle Bags of Seeds

Consider a small granary in a village. In the corner, piles of seed packets wait for the next planting season. They look harmless to the human eye. But a silent struggle is occurring within. *Aspergillus, Penicillium*, and *Fusarium* are minute fungi that invade seeds and feed on nutrients they have stored. Most of the seeds are dead or weak by planting time.Were you aware? Fungi can result in 20–30% of post-harvest seed losses in poor countries, threatening food security.

New problems and old solutions

Farmers have relied on artificial coatings and man-made fungicides for decades. They work—until they do not. This approach generates plastic waste, harms soil ecosystems, and deposits toxic residues.

"It's like placing seeds under armor that never wears off; it protects them at first but ultimately damages the battlefield."

A Nature-Inspired Solution

Now imagine that every seed is shielded by an eco-friendly, biodegradable coating instead of toxic chemicals.

What's Inside the Shield?

- Natural Polymers: cellulose, plant gums, chitosan (which occurs in fungus or shellfish), and starch.
- Nature-based antifungals consist of plant extracts, essential oils such as neem, cinnamon, or clove, and even beneficial bacteria.
- Together, they form a thin, porous sheet that is sufficiently soft to break down in soil but strong enough to exclude fungus.

Obstacles in the Way

- Of course, there are a few obstacles to any innovation:
- Scalability of production remains costly.
- Natural coatings can be influenced by heat and moisture.
- Application-specific standard protocols are still under development.

- But scientists believe that these obstacles can be overcome with advances in bio-based materials and nanotechnology.

Why This Matters: Benefits Beyond the Laboratory

- It is a solution of global consequence, not just for seed science:
- Green: Coatings break down naturally, so the soil is not contaminated with chemical residue.
- Improved Seeds, Improved Crops: Growers have a better beginning courtesy of higher rates of germination.
- Farmer-Friendly: More reliable harvests, reduced fungicide expenses, and less loss are all part of healthier seeds.
- Improvement of Food Security: Seed conservation guarantees future food availability for growing population.

Challenges: Not a Fairy Tale (Yet)

Biodegradable coatings are not perfect, as with any new technology. There are tremendous challenges in establishing routine procedures, ensuring a long shelf life, and taking production to scale. But science is quickly closing the gap, with field trials proving the idea works outside the laboratory and promising research into nano-coatings that dispense antifungal chemicals over time.

SEED STORAGE CHALLENGES VS. SOLUTIONS

Challenge	Impact on Seeds	Traditional Approach	Sustainable Alternative
Fungal contamination *(Aspergillus, Fusarium, Penicillium)*	Reduced germination and decay	Chemical fungicides	Biodegradable antifungal coatings
Long storage periods	Nutrient loss, poor vigor	Synthetic polymer coatings	Natural polymers, starch, chitosan, cellulose
Farmer losses	Financial instability food insecurity	High-cost chemical treatments	Cost-effective local bio-materials

MATERIALS USED IN BIODEGRADABLE ANTIFUNGAL COATINGS

Component Type	Examples	Role in Coating
Natural polymers	Chitosan, starch, cellulose, gums	Form protective film; biodegradable
Antifungal agents	Essential oils (e3. neem, clove, gums)	Inhibit fungal growth
Additives	Proteins (soy, gelatin), natural plasticizers	Enhance flexibility and coating adhesion

Biodegradable antifungal coatings are not only protection, but a promise, a promise that agriculture can be clean, sustainable, and progressive. Not only do we save crops, we are building hope for generations to come by protecting seeds in nature's own shield.

"The future is getting greener,seed by seed"

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Bionomics of Fruit Fly (*Bactrocera Spp.)* and Its Implications In Pest Management

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Diwakar Raj

Student, School of Agriculture and Environmental Sciences, Shobhit Deemed University, Meerut (U.P.)

Fruit flies belonging to the genus *Bactrocera* are among the most destructive pests of fruits and vegetables in tropical and subtropical regions of the world. They cause severe yield losses by ovipositing inside fruits, which results in tissue damage, premature fruit drop, rotting, and reduced market value. Their presence also restricts international trade because of strict quarantine regulations.

The study of their bionomics—including host preference, life cycle, reproductive potential, and seasonal abundance—is essential for developing sustainable management practices. *Bactrocera spp*. are highly fecund, adaptable to various climatic conditions, and capable of multiple generations per year. This article reviews the major aspects of fruit fly bionomics and highlights eco-friendly management strategies under the framework of Integrated Pest Management (IPM).

Fruits and vegetables are vital components of the human diet, providing essential nutrients and contributing significantly to farmers' income. However, production and marketing are severely hampered by insect pests, among which fruit flies (*Bactrocera spp*.) are of foremost importance. In India, yield losses due to fruit flies range between 30–80%, depending on the host and climatic conditions. Besides reducing productivity, fruit flies also downgrade the quality of produce, leading to rejection in domestic and export markets.

The genus *Bactrocera* (family: Tephritidae) comprises more than 400 species, of which several are economically important. Common species found in India include the melon fruit fly (*Bactrocera cucurbitae*), oriental fruit fly (*Bactrocera dorsalis*), and guava fruit fly (*Bactrocera correcta*). Their polyphagous nature, high reproductive rate, and adaptability make them one of the toughest challenges in horticultural pest management

Bionomics of *Bactrocera Spp.*

Host Range

Fruit flies are highly polyphagous pests. They attack more than 250 plant species, including mango, guava, papaya, citrus, banana, cucurbits, and other commercial fruits. Host preference varies with species and availability, but cucurbits and tropical fruits are the most affected.

Life Cycle

The development of Bactrocera spp. involves four distinct stages—egg, larva, pupa, and adult:

1. Egg Stage

- Females puncture the fruit skin using their ovipositor and deposit eggs beneath the peel.
- Each female can lay 600–800 eggs in her lifetime.
- Eggs are small, white, and hatch within 1–2 days under favorable conditions.

2. Larval Stage (Maggot)

- The hatched maggots feed on fruit pulp, creating galleries inside.
- Larval duration lasts for 5–7 days, depending on temperature.
- Infested fruits often show premature drop and rotting.

3. Pupal Stage

- Mature larvae leave the fruit and pupate in the soil at a depth of 1–5 cm.
- Pupal period is around 7–10 days, though it varies with climate.

4. Adult Stage

- Adults are strong fliers, capable of dispersing up to 20 km.
- They live for 1–3 months, with multiple mating and oviposition cycles.
- Adults are attracted to methyl eugenol, a chemical widely used in traps.

Seasonal Incidence

Fruit fly population peaks during warm and humid conditions, usually coinciding with the fruiting season (April–September in India). Higher relative humidity favors oviposition and larval survival. In northern India, two to three peaks are observed annually, while in southern regions populations may persist year-round.

Reproductive Potential

- Females lay eggs in clusters inside fruit tissue.
- Fecundity is high, with a single female capable of laying hundreds of eggs.
- This high reproductive rate, coupled with overlapping generations, makes control difficult.

Dispersal And Adaptability

- Adults are excellent fliers and spread rapidly to new orchards.
- Their adaptability to different agro-climatic zones enables them to invade new regions, often becoming quarantine pests.

Economic Importance

1. Yield Loss: Direct feeding damage by maggots causes rotting and fruit drop.

2. Quality Deterioration: Infested fruits lose market value and consumer acceptability.

3. Trade Restrictions: Infestation leads to rejection of export consignments due to quarantine rules.

4. **Increased Cost of Cultivation**: Farmers spend more on pesticides and

Management Strategies

1. Cultural Methods

- Field Sanitation: Collect and destroy infested and fallen fruits.
- Crop Rotation: Avoid continuous cultivation of host crops.
- Early Harvesting: Harvest fruits before peak oviposition.
- Deep Burial: Infested fruits should be buried at least 50 cm deep.

2. Mechanical and Physical Methods

- Fruit Bagging: Covering young fruits with paper or cloth bags prevents oviposition.
- Trapping: Use methyl eugenol lure traps or pheromone traps to attract and kill males.

3. Biological Control

- Parasitoids: Species such as Opius compensates and Diachasmimorpha longicaudata attack fruit fly larvae.
- Predators: Ants, spiders, and birds feed on pupae and adults.
- Entomopathogens: Fungal pathogens like Beauveria bassiana show promise.

4. Chemical Control

- Bait Sprays: Protein hydrolysate mixed with insecticides attracts adults and reduces population.
- Spot Application: Targeted spraying instead of blanket coverage reduces pesticide load.
- Fumigation: For export consignments, fumigation ensures quarantine compliance.

5. Integrated Pest Management (IPM)

- The most sustainable approach is to integrate multiple methods:
- Field sanitation + bait traps + biological control + need-based chemicals.
- Farmer awareness and community participation are crucial for area-wide management.

Conclusion

Fruit flies (Bactrocera spp.) are a serious threat to fruit and vegetable production in India and across the tropics. Their high reproductive capacity, wide host range, and adaptability make them difficult to control. However, a thorough understanding of their bionomics provides the foundation for developing eco-friendly and sustainable management strategies. Adoption of Integrated Pest Management (IPM), involving cultural, mechanical, biological, and judicious chemical methods, is essential to minimize losses, improve fruit quality, and maintain export standards.

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