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PROCEEDINGS OF

NATIONAL SYMPOSIUM ON INNOVATIVE APPROACHES FOR INTEGRATED PEST MANAGEMENT (IPM NEXUS 25)

OCTOBER 10, 2025

Organized by
Department of Entomology
SRM College of Agricultural Sciences
SRM Institute of Science and Technology
Baburayanpettai, Chengalpattu Dist. - 603 201

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SRM COLLEGE OF AGRICULTURAL SCIENCES

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Proceedings of

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10th October, 2025

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Department of Entomology

SRM College of Agricultural Sciences, SRMIST

Baburayanpettai, Chengalpattu-603 201

Tamil Nadu

October 2025

Citation

Proceedings of National Symposium on Innovative Approaches for Integrated Pest Management (IPM Nexus 25) held at SRM College of Agricultural Sciences, SRMIST, Baburayanpettai, Chengalpattu, Tamil Nadu, India on 10th October, 2025.

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ISBN 978-93-90357-33-8

9 789390 357338

DOI: http://dx.doi.org/10.22573/spg.025.epro/S/040

Published By,

Skyfox Publishing Group

Skyfox Press

#1789, Medical College Road

Thanjavur-613004

Tamil Nadu, India.

ACKNOWLEDGEMENT

We are thanking SRMIST for providing funding support for organizing this **National Symposium on Innovative Approaches for Integrated Pest Management (IPM Nexus 25)** on October 10, 2025 at SRM College of Agricultural Sciences, Acharapakkam Campus.

We are thankful for **Southern Indian Scientific Corporation (Chennai), "LYNX" Lawrence & Mayo (Chennai) and Krishnaaram Laboratories (Chennai)** for their financial grant for organizing this National Symposium.

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MESSAGE

It gives me immense pleasure to convey my warm greetings to the Department of Entomology, SRM College of Agricultural Sciences, SRMIST, for organizing the *National Symposium on Innovative Approaches for Integrated Pest Management (IPM Nexus 25)* on 10th October 2025.

Integrated Pest Management (IPM) has emerged as a vital approach in ensuring sustainable crop production, safeguarding the environment, and reducing reliance on chemical pesticides. This symposium provides a timely and meaningful platform for researchers, academicians, students, industry professionals, and policymakers to share innovative ideas, technologies, and field experiences that will contribute to the advancement of IPM strategies.

I am glad that the proceedings of abstracts have been compiled with an ISBN, which will serve as a valuable reference for scholars and practitioners across the country. Such documentation not only reflects the academic rigor of the symposium but also strengthen the visibility and impact of the knowledge shared.

I congratulate the organizing team for their dedicated efforts and extend my best wishes for the grand success of the symposium. I am confident that the deliberations and discussions will inspire new collaborations and contribute significantly to sustainable agricultural development.

Dr. M. Jawaharlal
Convener- IPM Nexus 25

IPM NEXUS 25: INDEX OF ABSTRACTS & FULL LENGTH PAPERS

NANOTECHNOLOGIES FOR PLANT HEALTH MANAGEMENT

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ABSTRACT

Nanotechnology is a fascinating field of science dealing with manipulation of atom by atom and thus products and processes evolved from nano science are the most précised ones that are impossible to achieve by the conventional systems. Nano particles are very tiny, measuring a dimension of one-billionth of a metre (10-9 m) or one in 100 Crores, giving extensive surface area for nanomaterials to react and exhibit the reactions of the pathogens at the atomic scale. Nanotechnology is being exploited in a wide spectrum of agricultural sciences of which early detection of plant diseases, smart delivery of inputs and quarantine of plant diseases are quite significant.

Early detection of plant diseases is utmost essential to save the crop well before the symptoms exhibited. Quick on-site detection of plant pathogens using nano based kits such as Lateral Flow Immunoassay Devices (LFIDs) using gold nanoparticles, loop mediated isothermal amplification (LAMP) combined with LFD, Quantum dots (QDs), Nano barcode and Bio-imaging. These methods have high sensitivity, specificity, precision and speed of the pathogen detection that assist in high- throughput analysis and rapid response time to take suitable remedial measures.

Nano-Formulations are developed using active ingredients that are unequivocally demonstrated to possess pesticide value against devastating diseases. Persistence of agro chemicals in the initial stage of crop growth helps in bringing down the spread of the disease below economic threshold level and to have an effective control for a longer period. Hence, the persistence of pesticides is one of the most cost-effective and versatile means of controlling insect pests. In order to protect the active ingredient from the environmental conditions and to promote persistence, a nanotechnology approach "encapsulation (nano / micro)" can be used to improve the insecticidal value. Microencapsulation comprises nano-sized particles of the active ingredients being sealed by a thin-walled sac or shell (protective coating). Nanoencapsulation of pesticides allows for proper absorption of the chemical into the plants unlike the case of conventional formulations. Nano-encapsuation of insecticides, fungicides or nematicides will help in producing nano-formulations which offer effective control of pests

while preventing residues in soil.

In addition to the encapsulated forms of insecticides, some of the nanoparticles are being used as effective strategy to protect the crops from damage by pests and diseases. Surface modified hydrophobic nanosilica has been successfully used to control a range of agricultural pests. The successful use of silver nanoparticles (Ag NPs) in diverse medical streams as antifungal and antibacterial agents has led to their applications in controlling phytopathogens. Ag NPs with broad spectrum of antimicrobial activity reduces various plant diseases caused by spore producing fungal pathogens. The effectiveness of Ag NPs can be improved by applying them well before the penetration and colonization of fungi within the plant tissues. The small size of the active ingredient effectively controls fungal diseases like powdery mildew. However, it was also observed that a very high concentration of nano-silica silver produced chemical injuries on the cucumber. The use of Ag NPs as an alternative to fungicides for the control of sclerotium forming phytopathogenic fungi was also investigated. Exposure of fungal hyphae to Ag NPs caused severe damage by the separation of layers of hyphal wall and collapse of hyphae. The efficacy of Ag NPs in extending the vase life of gerbera flowers was also studied and the results show inhibited microbial growth and reduced vascular blockage which increased the water uptake and maintained the turgidity of gerbera flowers. Apparently, the use of biocide containing polymeric nanoparticles for introducing organic wood preservatives and fungicides into wood products thereby reducing the wood decay was also studied. Among the nanoparticles, Ag NPs are widely used accounting for more than 30 per cent of the nano-based commercial products in the world.

"Smart Delivery Systems" for agriculture can possess timely controlled, spatially targeted, self regulated, remotely regulated, pre-programmed, or multi-functional characteristics to avoid biological barriers to successful targeting. Smart delivery systems can monitor the effects of delivery of nutrients or bioactive molecules or any pesticide molecules. In the smart delivery system, a small, sealed package carries the drug which opens up only when the desirable location or infection site of the human or animal system is reached. This would allow judicious use of antibiotics than otherwise would be possible. A molecular-coded "address label" on the outside of the package could allow the package to be delivered to the correct site in the body. Similarly, implanting nanoparticles in the plants could determine the nutrient status in plants and take up suitable remedial measures well before the malady causes yield reduction in crops. The fertilizer or irrigation requirement of crops can be scouted by nanotechnology. The exciting possibility of combining agricultural science and nanoscale technology into sensors holds the potential of increased sensitivity and therefore a significantly reduced response- time to sense field problems. "Smart" delivery systems could contain on board chemical detection and decision-making capability for self-regulation that could deliver active chemical molecules or nutrients as needed. Remote activation and monitoring of intelligent delivery systems can assist agricultural growers of the future to minimize antibiotic and pesticide use.

Keywords: Nanoproducts, Ag NPs, Diseases, Sustainable pest management.

ROLE OF PLANT PRODUCTS IN INTEGRATED PEST MANAGEMENT

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ABSTRACT

Plant-derived compounds are alternatives to synthetic pesticides with varied modes of action and contribute to sustainable agriculture. They can be insect antifeedants, repellents, deterrents, oviposition inhibitors showing direct insecticidal effects, hormonal imbalance causing growth abnormalities, besides, altering insect behaviour and physiology while generally being safer to nontarget organisms and the environment. The active phytochemical classes include alkaloids, terpenes, phenols, coumarins, flavonoids, quinone, glycosides, quassinoids, tannins, lignans, steroids, polyacetylene, and the like. For example, the members of Rutales contain limonoid, whereas the plants of Brassicaceae contain mustard oil in general, but a few species have cardenolides or cucurbitacins. Other families may diversify their deterrents, eg, non-protein amino acids (l-canavanine in jack bean), alkaloids, cyanogens, and iso flavonoids in Leguminosae.

The common botanical compounds with pesticidal activity that have been successfully isolated and commercialized include azadiractin from neem (*Azadirachta indica, A. juss),* and pyrethrin from pyrethrum, *Chrysanthemum cinerariifolium* (Trevir). Other plants used in pest management include garlic *Allium sativum* L., turmeric *Curcuma longa* L., rosemary marry *Salvia rosemarinus spenn*, ginger Zingiber officinale Roscoe, and thyme *Thymus vulgaris L.*

With recent advances in research, the development of model tobacco and tomato plants with genetically engineered pyrethrin genes expressing higher levels of resistance is made possible. Likewise, engineering genes Bowman-Birk type protease inhibitors (BBIs) of cowpea or blackgram into plants like tobacco, rice, and wheat enhanced resistance against coleopteran and lepidopteran pests. The development of nanoemulsions of compounds of herbal plants and pesticidal plants makes pest management more effective and sustainable. The advent of drone technology offers a solution to pesticide drifting with precise application to site-specific fields.

Hence, integration of botanicals in integrated pest management ensures major benefits to the farmers, including food safety, reduced pest levels, improved quality of produce, realizing premium prices, and guaranteed market access.

Keywords: Pesticidal plants, Phytochemicals, non-target organisms, Environment, Sustainable agriculture.

INNOVATIVE ECOLOGICAL APPROACHES FOR ENHANCING NATURAL ENEMY DIVERSITY TO STRENGTHEN CONSERVATION BIOLOGICAL CONTROL

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Abstract

Conservation Biological Control (CBC) is a cornerstone of sustainable pest management, emphasizing the protection and enhancement of naturally occurring predators, parasitoids, and entomopathogens. Innovative ecological approaches that enhance natural enemy diversity have emerged as effective and eco-friendly alternatives to chemical pesticides, offering stability and resilience to agroecosystems. Ecological engineering and habitat manipulation are among the most widely adopted strategies. Planting flowering strips and nectar-rich plants such as buckwheat (*Fagopyrum esculentum*), coriander (*Coriandrum sativum*), and marigold (*Tagetes* spp.) enhances the longevity and fecundity of parasitoids like *Trichogramma* and *Aphidius* species. In rice ecosystems, bund cropping with cowpea and sesame attracts coccinellids and chrysopids that suppress planthopper populations. Similarly, cotton intercropped with alfalfa enhances spider and lady beetle abundance, reducing whitefly and aphid infestations. Landscape diversification also plays a critical role in strengthening CBC. Hedgerows, non- crop habitats, and refuge patches provide shelter and alternative prey, ensuring the persistence of natural enemies during off-seasons. Push–pull strategies in maize, employing Desmodium as an intercrop and Napier grass as a border crop, not only suppress stem borers but also enhance parasitoid activity.

Besides, semiochemicals, particularly herbivore-induced plant volatiles (HIPVs) and synthetic kairomones, represent a rapidly advancing frontier in enhancing natural enemy efficiency. Compounds such as methyl salicylate (MeSA) and (Z)-3-hexenyl acetate have been shown to attract lady beetles, lacewings, and hoverflies to crop fields. Recent developments include slow-release dispensers and nanotechnology-based formulations that provide sustained emission of attractants, improving field- level efficacy. For instance, controlled release of MeSA has successfully enhanced predator recruitment in apple and soybean systems, leading to improved suppression of aphids and mites. Combining floral resources with semiochemical lures has been demonstrated to synergistically increase parasitoid foraging efficiency, creating multifunctional habitats that stabilize natural enemy populations.

The integration of ecological approaches with semiochemical tools represents a novel strategy for precision conservation biological control.These approaches reduce pesticide dependency, enhance biodiversity, and provide ecosystem services beyond pest regulation, including soil fertility and pollinator safety. The future of CBC lies in combining habitat manipulation, semiochemicals, and selective bio-rational inputs to develop climate-resilient, scalable, and sustainable pest management systems.

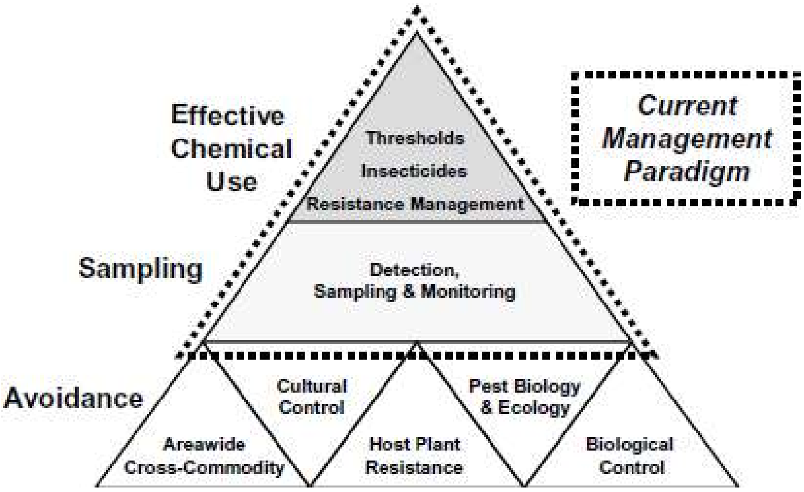
Introduction

Biological control is a cornerstone of sustainable pest management, offering an alternative to chemical insecticides by harnessing the potential of natural enemies and ecological processes. The use of biological control agents is one approach to reduce the undesirable ecological and health problems associated with overuse of chemical insecticides in agro ecosystems (Thoming, 2024). Biological control is a naturally occurring phenomenon and the biocontrol agents act on the crop pests and maintain them at certain densities. However, loss of biodiversity in intensive farming systems has undermined natural enemy communities and weakened pest suppression. To address these issues, historically, two primary directions have shaped biological control: conservation of naturally occurring beneficial organisms and augmentation through mass rearing and release (Gurr *et al.,* 2012). Over the last four decades, research has expanded beyond these ecological frameworks to include tritrophic interactions - linkages between plants, herbivores, and natural enemies mediated by infochemicals. These advances have illuminated how plants can "recruit bodyguards" by emitting volatile cues upon herbivore attack, enhancing the effectiveness of predators and parasitoids. Either it is conservation and enhancement or mass culture and release, a thorough knowledge of the crop ecosystem and the pests occurring is essential for successful implementation of the biocontrol programmes. Conservation biological control has emerged as a cornerstone of sustainable pest management. Rather than relying solely on external releases of natural enemies, it emphasizes the protection, enhancement and diversification of naturally occurring predators and parasitoids in agroecosystems.

This review integrates classical ecological approaches (habitat and cultural management, conservation strategies) with modern advances in infochemical-mediated pest regulation. By merging these perspectives, we highlight a hybrid approach that builds resilient agroecosystems capable of sustaining crop health with minimal chemical input.

Conservation and Enhancement of Natural enemies

Many avoidance strategies forming foundation of the management pyramid remains untapped. Integration of ''avoidance'' strategies into overall management programs improve the efficiency of IPM. Agricultural intensification efforts should be designed based on ecological principles (Bommarco *et al*., 2013) and the ecological intensification should be in favour of ecosystem services like natural enemies.



1. Selective application of chemical insecticides

Insecticides available are all potent and even in minute quantities (far less than that required against the target pest) is sufficient to eliminate many parasitoids, particularly micro-hymenopterans (Wilby & Thomas, 2002). If they are persistent, then the damage will be more. Hence, when a chemical insecticide has been used in a crop, the release of the natural enemies should be postponed until the toxicity has dissipated. Pest based selective use of insecticides like systemic / acaricides etc rather than broad spectrum can spare natural enemies. Also, use of chemicals should be avoided, when the activity of the natural enemy is high in a crop. However the decision has to be made taking into account other aspects of management.

2. Preservation of inactive stages of natural enemies

The preservation of inactive stages is most critical when there is a small reservoir or none at all of natural enemies outside the cropped area. At the initial establishment site of the parasitoids of the cereal leaf beetle, *Oulema melanopus* in Michigan, a high percentage of the major parasitoid, *Tetrastichus julis* overwintered in the soil of oat stubble. Hence a portion of the oat stubble was not ploughed until the parasitoids had emerged in the spring, resulting in a rapid build up of the parasitoid (Stehr and Haynes, 1972).

3. Crop Management Practices

Field-level management strongly affects trophic interactions. Reduced tillage preserves soil-dwelling predators, while intercropping and delayed sowing alter pest phenology to favour natural control (Bengtsson *et al*., 2005). Crop rotation and diversified planting enhances habitat heterogeneity, indirectly benefiting predator populations (Altieri, 1999). Conversely, pesticide use and nitrogen fertilization reduce natural enemy abundance (Koss *et al*., 2005; Swift *et al*., 1996). Thus, crop management should integrate ecological considerations alongside agronomic goals.

4. Avoidance of harmful cultural practices

Cultural control is a valuable part of managing pests but ploughing, hoeing, mowing, burning etc., can be equally harmful to natural enemies. The effects of these should be fully evaluated before such operations and harmful ones eliminated or modified. The strip harvesting of alfalfa in California has resulted in much greater survival of natural enemies and the hosts necessary to keep them active. In sunflower, early sowing favours the build up of important predators like *Chrysopa* and ladybird beetles (Arora *et al.,* 1998).

5. Maintenance of diversity and necessary hosts

Biodiversity enhances pest suppression through complementarity, whereby different natural enemies exploit pests at different times, life stages, or microhabitats (Straub *et al*., 2008; Snyder, 2019). The maintenance of diversity is frequently a necessary part of many other measures since it may provide needed hosts, sources of food, over wintering sites, refuges etc. Diversity in itself is not essential but most natural enemies have evolved in communities much more diverse than crop communities, hence it is reasonable to expect the right kinds of diversity to be essential. Hambleton (1944) illustrated the value of crop diversity in the irrigated Canete Valley in Peru where the tobacco budworm *Heliothis virescens* reduced cotton yields by 30-40% following the planting of nearly entire valley to cotton. Arsenical insecticides had no effect and hence farmers were encouraged to plant winter crops such as corn, flax, beans and sweet potatoes which supported non-economic populations of various lepidoptera including *H. virescens.* These species provided the hosts necessary to maintain through the winter the population of predators and parasitoids that controlled *H. virescens* during the long summer growing season.

Whitman and Norduland (1994) found that parasitization of *Helicoverpa zea* (Boddie) eggs by *Trichogramma pretiosum* females was relatively high in plots of tomato but almost non existent in adjacent plots of corn. It was found that the presence of volatile stimuli from tomato plants in corn fields resulted in increased rates of parasitization by *T. pretiosum*. Seasonal and diurnal differences among predators (e.g., day-active vs. nocturnal species) further extend pest suppression across temporal niches. However, risks such as intraguild predation and redundancy may reduce effectiveness (Rosenheim *et al*., 1993; Straub and Snyder, 2006).

Structurally complex habitats and abundant alternative prey minimize these risks by dampening interference (Finke and Denno, 2002; Halaj and Wise, 2002).

6. Alternate hosts

The right life stages of the host may not be available at the right time or the right place to ensure the survival of natural enemies throughout the year. Manipulating the crop, planting different crops nearby, leaving some weeds or providing diversity in other ways is usually essential in providing for alternate hosts.

Alternative or non-pest hosts provide a continuous food source for natural enemies during pest-scarce periods, ensuring their survival and availability when pest outbreaks occur. These hosts can act as ecological reservoirs, supporting parasitoid and predator populations across cropping cycles. For example, parasitoids often rely on alternative lepidopteran or aphid hosts that persist in nearby vegetation, thereby stabilizing their populations. Such ecological engineering ensures that beneficial are not entirely dependent on target pests, making them more reliable allies in pest suppression. Besides, provision of artificial food also conserves beneficial fauna at times. For example, many parasitoids and predators require foods (nectar, pollen and honey dew) frequently not available in monocultures. In irrigated monoculture desert areas of California artificial honeydew and pollen in the form of food sprays have induced the early oviposition of naturally present Chrysopids and Coccinellids in treated fields resulting in significantly lower populations of aphids in alfalfa and of bollworms in cotton (Hagen *et al*., 1970). The abundance of the predatory mite *Amblyseius hibisci* in avocado orchards in California was related to the availability of pollen, even when prey mites were absent. Although promising, the practical deployment of alternative hosts requires careful management to avoid creating refuges for secondary pests.

Few practices that could preserve natural enemies' population are tabulated below.

Crop	Natural enemy	Pest	Practice
Sweet pepper, ornamental crops	Syrphids, lacewings Predatory mites, *Orius laevigatus, O. majuscules O. insidiosus*	White flies, thrips, aphids	Plants providing pollen and plant sap as food sources for natural enemies like sweet alyssum, coriander, *Ricinus communis* and flowering ornamental
Cucumber, chrysanthemum	predatory mites *Amblyseius swirskii* & *Euseius scutalis*,	Thrips, whitefly	Spraying or dusting artificial or natural food supplements onto the crop. i.e. corn pollen, apple pollen, *Typha latifolia* pollen

Cereal crops	Aphid parasitoids	Cereal aphids	Introducing non-crop plants harbouring the prey species
Chrysanthemum	Phytoseiid predatory mites	Spider mite	Applying yeast and sugars for astigmatic mites that are suitable prey for phytoseiid predatory mites
Rose plants	predatory mites	Spider mites	Providing oviposition sites and shelters: Sweet pepper was used by predatorymites for oviposition.
Cotton, wheat, tomato	*Orius* spp., lacewings, lady beetles	Aphids, thrips, leaf-feeders	Induced plant responses that attract and/or retain natural enemies
Wheat	*Orius* spp., lacewings, lady beetles	Aphids, thrips, leaf-feeders	Mitigation of pesticide side-effects by selecting pesticides that are compatible with natural enemies

1. **Artificial shelters**

Provision of artificial shelters in the crop helps the natural enemies to exert their influence on the insect pest. In North Carolina, substantial reduction of tobacco hornworms was achieved by predacious *Polistes* wasps following the erection of nesting shelters near field margins.

2. **Reduction of undesirable predators**

In some cases the desirable natural enemies are selectively fed by predators thereby affecting the efficiency of the parasitoid. The biological control of the walnut aphid, *Chromaphis juglandicola* by a different ecotype of *Trioxys pallidus* from Iran has been affected in some areas of California by selective predation of parasitized aphids in preference to unparasitized aphids by the Argentine ant, *Iridomyrmex humilis* (Frazer and van den Bosch, 1973).

3. Influence of Plant Traits and Breeding

Plant morphology and phytochemistry influence natural enemy performance. High trichome density in tomato, for example, increases egg parasitism by *Trichogramma* spp. Advances in plant breeding and genetic engineering now enable the incorporation of natural enemy-enhancing traits, such as rapid emission of herbivore-induced volatiles (Gould, 1998).

4. **Control of honeydew feeding ants**

Honeydew-feeding ants can make the biological control of honeydew-producing species such as scales, mealybugs and aphids unsatisfactory because of interference with natural enemies (Styrsky and Eubanks, 2007)

5. Favourable temperature

Among the weather factors, temperature plays a major role in the effectiveness of parasitoids. The effect is more on parasitoids than on predators. Higher/extreme temperature usually affects the survival of certain delicate hymenopteran parasitoids. Besides this, beyond optima, the sex ratio of the progenies is also affected. In case of the egg parasitoid, *Trichogramma chilonis* beyond 31°C only males are produced (Prasad and Prasad, 2023).

6. Role of Semi-natural Habitats

Semi-natural habitats-hedgerows, meadows, fallows, and woodlots—provide stable resources such as pollen, nectar, and alternative prey, supporting diverse enemy communities (Marshall, 2004). These habitats act as refuges and overwintering sites, enabling enemy populations to persist when crops are unavailable (Pickett *et al*., 2000; Rusch *et al*., 2010). Studies showed that proximity and connectivity of these habitats enhance enemy spillover into crops, thereby stabilizing pest suppression (Bianchi *et al*., 2006).

7. Avoidance of dust

Dust created in the farms by farm operations affect the efficiency of the natural enemies. Road dust and other dusts have been shown to drastically reduce the effectiveness of some natural enemies in California while having little effect on the hosts.

Innovations in Conservation Biological Control (CBC)

Recent innovations combine ecological knowledge with practical farming strategies. CBC efforts increasingly aim to deliver multiple ecosystem services like pollination, soil fertility, and climate resilience alongside pest suppression (Gurr *et al.,* 2016; Karp *et al*., 2018). Plant volatiles, pheromones, and synthetic attractants can selectively enhance natural enemy foraging efficiency (Pickett and Bugg, 1998; Gontijo, 2019). Refuge strips combining bunch grasses for ground predators and floral resources for parasitoids exemplify ecological engineering that fosters complementary natural enemies (Snyder, 2019). Leaving crop residues increases habitat heterogeneity, reduces intraguild predation and enhances prey availability (Rowen *et al.,* 2019).

Chemical Ecology / Semiochemicals in Conservation Biological Control

Chemical ecology explores how chemical signals mediate interactions between organisms, particularly between plants, pests, and natural enemies. Semiochemicals such as kairomones, allomones, and synomones play a vital role in enhancing host-finding efficiency of parasitoids and predators. For instance, herbivore-induced plant volatiles (HIPVs) can attract parasitoids like *Trichogramma* spp. to infested plants, thereby improving natural enemy recruitment. Understanding these complex chemical- mediated interactions has enabled researchers to manipulate agroecosystems in ways that boost biological control while reducing pesticide dependency.

Natural enemies may also respond to odours like sex pheromones or alarm pheromones produced by their prey / host species. Compounds such as methyl salicylate (MeSA) and (Z)-3-hexenyl acetate have been shown to attract lady beetles, lacewings, and hoverflies to crop fields. Recent developments include slow-release dispensers and nanotechnology-based formulations that provide sustained emission of attractants, improving field-level efficacy. For instance, controlled release of MeSA has successfully enhanced predator recruitment in apple and soybean systems, leading to improved suppression of aphids and mites. Some of the examples are tabulated below.

Crop	Semio-chemicals	Effect	Reference
Cotton	Pink bollworm mating- disruption chemicals	Predators increased by 3-fold	(McVeigh *et al*., 1983)
Apple	Iiridodial-methyl salicylate	*Chrysopa oculata* (8-145 nos.) & *C. nigricornis* (86-446 nos.) than control trees (0-3 & 0-7nos.)	(Jones *et al.,* 2011)
Chinese cabbage	E-β-farnesene lures	9-41 parasitised aphids/20 plants compared to 5-19 parasitised aphids in controls	(Cui *et al.,* 2012)
Turnip	Methyl salicylate lure	More *Diadegma semiclausum* (1.6-7.2 wasps) than control (1.4-6.4 wasps)	(Orre *et al.* ,2010)
Citrus	Lavandulyl senecioate lures	19-51 *Anagyrus* sp. from citrus mealybug, *Planococcus citri* than in control with 0-20 wasps	(Franco *et al.,*2011)
Broccoli	Treated with allyl isothiocyanate	Parasitism in aphid increased from 8.5 to 22.5%	(Titayavan & Altieri 1990)

Challenges and Research Gaps

While laboratory studies have elucidated mechanisms of tritrophic signaling, translating them to complex field environments remains challenging. Interactions among multiple natural enemies, variability in volatile release across cultivars, and climatic influences demand long-term, landscape- scale studies (Turlings *et al*., 1995).

Innovative Hybrid Approaches

Overall, integrating ecological and infochemical approaches offers a synergistic framework for biological control. Key hybrid strategies include:

1.Habitat Manipulation + Volatile Recruitment: Designing diverse crop landscapes while deploying synthetic HIPVs or natural plant volatiles to attract natural enemies.

2.Breeding for Multi-Trait Resistance: Developing crop cultivars with both direct resistance (secondary metabolites, trichomes) and indirect resistance (enhanced volatile emission).

3.Landscape-Level Push–Pull Systems: Combining cultural diversity with semiochemical traps to manage pests across heterogeneous fields.

4.Biotechnology and Smart Delivery: Engineering plants to release volatiles at low infestation levels, coupled with slow-release dispensers of synthetic kairomones. Such integrative models not only strengthen natural enemy efficacy but also build resilience against pest adaptation and climate change.

Conclusion

When we decide to employ biocontrol as a component of IPM, a thorough knowledge of the crop ecosystem, weather conditions, pests occurring on the plants, their life cycle, already occurring natural enemies, crop damage level, etc. is necessary. Only after careful consideration of the prevailing crop condition and also the market situation we can employ appropriate biocontrol agent for obtaining maximum benefits.

Conservation biological control represents an ecologically sound and sustainable alternative to chemical-intensive pest management. The combined use of alternative hosts, chemical ecology, and semiochemicals has demonstrated significant potential in enhancing the abundance and diversity of natural enemies. By integrating these innovative approaches, agricultural systems can become more resilient, productive, and environmentally sustainable. The success of these strategies will ultimately depend on interdisciplinary research, farmer engagement, and policy support aimed at reducing chemical reliance and promoting ecological intensification.

Future Perspectives

Despite promising advances, several challenges remain in strengthening conservation biological control. The impact of climate change on multitrophic interactions is poorly understood, and the long- term effectiveness of alternative host strategies in different agroecological contexts requires further study. There is also a need for molecular tools to trace trophic linkages and identify cryptic species of natural enemies. Farmer adoption can be limited by a lack of awareness or short-term economic considerations. Future research should focus on developing scalable, farmer-friendly technologies that combine ecological engineering with innovative chemical tools.

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EMERGING PESTS AND THEIR MANAGEMENT: A CASE STUDY WITH *Phenacoccus saccharifolii* OF SUGARCANE

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ABSTRACT

Nowadays minor pests have become major ones and threaten the cultivation of economically important crops worldwide. It is very challenging to manage such emerging pests as one has to study almost all the entomological aspects of the pests including, but not limited to their basic taxonomy, biology, ecology, host plant resistance, biological control and insecticide toxicology. Further, appropriate management strategies have to be developed within no time as the new pests are more devastating in nature. The mealybug, *Phenacoccus saccharifolii* (Green) (Hemiptera: Pseudococcidae), a lesser- known pest, has become a major threat to cane cultivation in India and Tamil Nadu, in particular. Though this species has been reported to occur on sugarcane in as early as 1942 in the Bihar State of India, it had never ever been considered as a pest of sugarcane until 2021. It has now emerged as a major pest of sugarcane and warranting insecticidal interference to protect the crop from being perished. Since the infestation by *P. saccharifolii* at initial stage is generally restricted between -1 and -3 leaves of sugarcane, it is often unnoticed by the farmers and cane developmental personnel. If unnoticed at early stage, the central leaf whorl becomes rotten and the apical growth gets arrested leading to stunted growth. A novel and reliable method of estimating yield loss due to this pest has been developed and the same has been employed to assess the loss in the ratoon crop of cv. Co 11015. The yield loss due to this pest in cv. Co 11015 has been estimated to be 7.1 tonnes/ha at 10% level of incidence. Almost all the entomological aspects of this pest have been studied at the ICAR-SBI and the pest is now manageable with the adoption of appropriate plant protection measures. A study on the detailed biology of this pest revealed that the male and female individuals could complete their life cycle in 21.9±1.2 and 39.2±1.6 days, respectively. Like other Pseudococcids, males undergo complete metamorphosis with pupal stage, while females undergo incomplete metamorphosis without a pupal stage. There were two and three instars in male and female sexes, respectively. The mean fecundity was observed to be 281±90 eggs/female and the eggs were laid in an ovisac during the oviposition period of 6.2±1.1 days. Parthenogenetic reproduction with amphitoky was also observed in this species. A three years extensive and intensive survey indicated that the plant crop suffers more as compared to the ratoon crop. Among the germplasm screened for their reaction against the mealybug, cv. CoV 09356 and Co 86032 were observed to be the most susceptible and least susceptible varieties, respectively. The solitary parasitoid, *Leptomastix sylvae* (Encyrtidae: Hymenoptera) was found to regulate the pest population to a considerable extent in the surveyed fields. The parasitism by *Aenasius hayati* has been found to be suppressed to a greater extent by the hyper parasitoid, *Promuscidea unfasciativentris* (Eriaporidae: Hymenoptera). *L. sylvae* was also found to reproduce parthenogenetically with the sex ratio skewed to male. Thiamethoxam was observed to be more toxic to this mealybug species. It was also observed to be harmful to the parasitoid, *L. sylvae.* All the granular insecticides evaluated for their efficacy against *P. saccharifolii* were found to be effective with more than 80% reduction in the population after two applications at their respective recommended doses. An integrated approach with the cultivation of less susceptible varieties like Co 86032, promotion of natural parasitism by dominant species like *L. sylvae* and need-based application of effective insecticides like thiamethoxam is being suggested for successful and sustainable management *P. saccharifolii* in sugarcane crop ecosystem.

Keywords: Sustainable pest management, Integrated approaches.

SMART PEST MANAGEMENT THROUGH IOT AND AI APPROACHES

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ABSTRACT

The agricultural sector faces unprecedented challenges due to the rising global population, erratic climate fluctuations, and the growing pressure to ensure food security in an environmentally responsible manner. In recent years, remarkable advances in smart pest management have been driven by the convergence of Internet of Things (IoT), artificial intelligence (AI), and remote sensing (RS) technologies. Modern pest monitoring increasingly relies on robust sensor networks, unmanned aerial vehicles (UAVs), GPS-enabled robotics, and cloud-based analytics, which collectively enable early detection of insect and disease outbreaks.

AI-powered computer vision and deep learning algorithms, in particular, provide highly accurate image-based identification and forecasting of key pests and diseases, moving beyond conventional manual scouting. Recent commercial deployments—such as precision spray systems that leverage AI for targeted herbicide application—demonstrate significant reductions in chemical inputs and environmental impact. Additionally, public–private initiatives have begun creating large, accessible datasets and scalable IoT infrastructures to support real-time, field-level pest detection and adaptive management decisions. Despite challenges related to data quality and limited digital access in rural regions, the rapid adoption of AI-enabled solutions in crop protection is already transforming integrated pest management (IPM) strategies by enhancing prediction, optimizing input use, and improving sustainability on a global scale (Nyakuri *et al*., 2025). These developments, reinforced by scalable IoT frameworks and real-time analytics, are fostering data-driven advances in pest monitoring, forecasting, and management, thereby ensuring higher productivity while minimizing input costs and safeguarding agro-ecosystem health.

Advances in micro-fabrication and embedded systems have also enabled the development of miniature electronic devices for recording plant health parameters. Radar, thermal infrared imaging, and high-resolution RGB (red, green, blue) and hyperspectral cameras are increasingly being deployed for real-time crop monitoring, which indirectly supports the detection of pest- or disease-induced stress. A notable example is the AI-based smart pheromone trap developed by the ICAR – Central Institute for Cotton Research to

overcome the limitations of conventional pheromone traps for monitoring the pink bollworm (PBW). In this system, trap catches of PBW adult moths are recorded as digital images and transmitted to a remote server via the GSM communication network, along with weather parameters recorded at fixed intervals. The remote server stores the data in cloud storage, where a machine learning algorithm (YOLO – You Only Look Once) identifies PBW moths and counts them in each time-stamped image. The processed information, including insect counts, trap images, and corresponding weather data, is then transmitted to end users via Android-based mobile and Windows-based desktop applications. By integrating real-time trap data with weather parameters, this system enables a better understanding of pest dynamics across wider areas, contributing to more reliable pest forewarning systems and improved management practices in cotton (Rameash, 2024).

AI tools are also being widely employed for insect pest identification, population counting, and the prediction of pest spread in major crop ecosystems. Machine learning algorithms and computer vision techniques play a central role in these applications, particularly for the classification and detection of plant diseases. Key image features such as color, texture, and edges are extracted from diseased leaf or insect pest samples, and the segmented images are processed through classification algorithms such as Support Vector Machines (SVM), Convolutional Neural Networks (CNN), and Artificial Neural Networks (ANN) (Ebrahimi *et al*., 2017).

Notable applications include disease identification in rice and cassava (Hassan and Maji, 2022), citrus disease classification using leaf images (Syed-AbRahman *et al*., 2022), and viral disease diagnosis in pulses (Joshi *et al*., 2021), all of which have demonstrated promising results using CNN- based object detection techniques. In cotton, CNN models have been developed to classify 13 insect pests, including Helicoverpa armigera, Aphis gossypii, and Anthonomus grandis. Similarly, diseases such as cercospora leaf spot (SVM), bacterial leaf spot (ANN), fusarium wilt (SVM), and ascochyta blight (CNN) have been detected with accuracies ranging from 80% to 96% (Toscano-Miranda *et al*., 2022).

The integration of IoT and AI holds considerable potential to address critical challenges faced by farmers, such as the judicious use of pesticides, reducing dependence on manual labour for pest monitoring, and enhancing crop productivity while safeguarding environmental and soil health. Nevertheless, several constraints remain. AI systems require extensive spatial and temporal datasets for model training and precise prediction. Developing location-specific algorithms demands substantial initial investment, concentrated research and development, and significant operational and maintenance costs. Moreover, poor internet connectivity and bandwidth limitations in rural and remote regions may restrict the deployment and adoption of IoT- and AI-based solutions. Despite these hurdles, rapid technological progress and growing investment by agricultural enterprises are accelerating the adoption of AI-driven tools for plant health management, offering promising support for progressive farming practices.

Keywords: AI technology, Sustainable pest management, pest and diseases.

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CYANOBACTERIAL EXTRACT AS BIOPESTICIDES AGAINST *Spodoptera frugiperda* IN SUSTAINABLE PEST MANAGEMENT

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ABSTRACT

In intensified agriculture, the long-term use of chemical pesticides to control pests has led to ecological imbalance, pesticide resistance. Ecological solution being viable alternative to manage pest in a sustainable way. Fall armyworms, scientifically called Spodoptera frugiperda, are polyphagous pests causing severe damage on more than eighty crop species worldwide and known to have surprising resilience to chemical approaches. In this study, food overlay bioassay is conducted to evaluate the effectiveness of cyanobacterial extracts, from Spirulina sp. and Nostoc muscorum, against the second instar larvae of *S.frugiperda*. An assessment was carried out on the extracts of *N.muscorum* obtained using hexane, petroleum ether, ethanol, and methanol. These extracts were subjected to evaluation for their lethal concentration (LC50) values and their effectiveness on biological parameters. It was noted that the hexane and petroleum ether extracts of *N.muscorum* showed the highest toxic effect, which was known by the lowest LC50 values also significant negative impact on larval and pupal duration, percent pupation, pupal and adult malformation, pupal weight, and further reduced adult emergence, fecundity, and longevity. Similar effects were exerted by Spirulina extracts, though the changes were not so. The results impart metabolites of cyanobacteria as a considerable as eco friendly alternatives for the green control of *S.frugiperda*, also providing an approach for the design and the utility of cyanobacteria-based biopesticides in integrated pest management approaches.

Keywords: Ecological pest control, Integrated pest management, *Spodoptera frugiperda*, Biopesticides, Cyanobacterial extracts

TOWARDS SUSTAINABLE PEST MANAGEMENT: INTEGRATING ECOLOGICAL ENGINEERING, BIOLOGICAL CONTROL AND AGROECOLOGICAL STRATEGIES

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ABSTRACT

The pursuit of sustainable agriculture has highlighted the urgent need to reduce reliance on synthetic pesticides and strengthen ecologically based pest management approaches. Across disciplines,ecological engineering, integratedpest management (IPM), and biologically based strategies converge on enhancing natural regulations of pest populations while safeguarding ecosystem stability, food security and farmer livelihoods. Push-Pull systems, conservation of natural enemies, and the strategic use of biological control agents represent promising pathways, yet their is challenged by inconsistent IPM implementation, limited farmer participation, and the uncertainties imposed by climate change. Recent advances in agroecological crop protection emphasize the integration of ecological principles at the field, farm and landscape levels,where biological control,habitat management and judicious chemical use can operate synergistically. Future progress requires adaptive management under changing climates, stronger farmer-centered approaches and interdisciplinary collaboration to achieve resilient, sustainable and scalable pest management systems.

Keywords: Ecological Engineering, Integrated Pest Management, Biological control, Agroecology, Climate change, Sustainable crop protection.

SUSTAINABLE CROP PROTECTION: THE FUTURE OF ECO-FRIENDLY PESTICIDES

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ABSTRACT

Modern agriculture's heavy reliance on synthetic pesticides hasled to a range of serious problems—soil and air pollution, disruption of ecosystems, health concerns for humans, and the growing issue of pestresistance. These challenges highlight the pressing need for safer, more sustainable alternatives. This study explores the potential of eco-friendly pesticides made from gadung tubers (Dioscorea hispida), a plant longvalued for its natural bioactive compounds. Using acombination of literature review, expert interviews, and field trials in Gowa, Indonesia, the research found that gadung-based pesticides effectively controlled key agricultural pests such as brown planthoppers and cocoa pod suckers, with mortality rates above 70%. Encouragingly, these biopesticides caused little harm to beneficial organisms or the surrounding environment. Their effectiveness lies in naturally occurring compounds like diosgenin and alkaloids, which disrupt the nervous systems of target pests, leading toparalysis and death. The study also points to the importance of developing improved formulations for greater stability and ease of use, along with farmer training programs to encourage adoption. When paired with organic farming practices, such eco-friendly innovations can significantly reduce dependence on harmful chemicals, protect biodiversity, and contribute to building a more sustainable, resilient, and productive agricultural future.

Keywords: *Dioscorea hispida* (Gadung tubers), Biopesticides, Paralysis, Diosgenin, Alkaloids

ENTOMOPATHOGENIC FUNGI AGAINST WHEAT APHIDS

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ABSTRACT

Pests making farmers often rely on chemical pesticides. Even though they are effective initially, these inputs have created long-term problems like degradation, ecological imbalance, resistance. To tackle this, ecological innovations offer sustainable alternatives that harness natural processes for pest regulation. Aphids such as *Rhopalosiphum padi* and *Schizaphis graminum* are the most destructive pests of wheat across the world , these pest are alternatives to chemical insecticides. By this study , it is clear that the pathogenic potential of two entomopathogenic fungi, Beauveria bassiana and Metarhizium anisopliae, under both lab and field conditions. In Lab,bioassays demonstrated that B. bassiana at a concentration of 1.05 × 10^{13} conidia/ml induced mortality rates of 83.4% in R. padi and 79.4% in S. graminum after seven days, showing outperforming M. anisopliae. In Field trials, involving three foliar applications at 15-day intervals, confirmed the superior performance of B. bassiana, achieving 69.3% and 66.3% mortality in R. padi and S. graminum, respectively. These findings are very strong biocontrol potential of B. bassiana against wheat aphids and support its integration into eco-friendly pest management strategies and a good alternative to synthetic insecticides.

Key words: Entomopathogenic fungi, Biological control, Pest management, Sustainable, Eco-friendly.

ECO-EFFICIENT PEST MANAGEMENT: HARMONIZING ENVIRONMENTAL AND ECONOMIC GOALS IN FARMING

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ABSTRACT

Sustainable pest management plays a vital role in modern agriculture by protecting crops while minimizing environmental harm and maintaining economic viability. Conventional pest control methods, largely dependent on chemical pesticides, have raised concerns due to their negative impacts on ecosystems, human health, and biodiversity. This review examines sustainable pest management approaches that incorporate ecological principles and economic factors. It explores methods such as Integrated Pest Management (IPM), biological control, and the application of environmentally friendly pesticides, evaluating their effectiveness in controlling pest populations and preserving ecological balance. The review highlights the importance of employing diverse strategies tailored to specific agricultural conditions, including crop types, pest species, and local environments. Furthermore, it discusses the economic advantages of sustainable pest management, such as cost reduction, enhanced crop yields, and improved long-term soil health. The paper concludes by stressing the need for ongoing research and innovation to develop pest management systems that are both ecologically responsible and economically practical, ensuring the sustainability of agricultural practices over time.

Keywords: Sustainable pest management, Integrated Pest Management (IPM), Biological control, Eco-friendly pesticides, Agricultural sustainability

SMART TECHNOLOGIES FOR POLLINATOR-SAFE INTEGRATED PEST MANAGEMENT

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ABSTRACT

Honeybees play a critical role in agriculture as pollinators, yet their survival is increasingly threatened by pests, diseases, pesticide exposure, and environmental stress. Advances in digital technologies are transforming Integrated Pest Management (IPM) into a more precise, predictive, and pollinator-friendly approach. Smart hive monitoring systems using IoT sensors enable early detection of colony stress and pest infestations, while remote sensing and GIS tools help identify pest hotspots and pesticide drift risks in cropping systems. Artificial intelligence and machine learning provide powerful tools for pest recognition, disease diagnosis, and predictive modelling to align pest control with pollinator safety. Decision support systems and mobile platforms further support farmers and beekeepers by integrating real-time data into safe and effective pest management practices. Robotics and precision spraying technologies also minimize chemical exposure to foraging bees. Together, these innovations represent a digital frontier in IPM, offering opportunities to protect honeybees, reduce chemical inputs, and enhance agricultural sustainability.

Keywords: Honeybee Conservation, Digital Integrated Pest Management (IPM), IoT Hive Monitoring, AI-based Pest and Disease Detection, Precision Agriculture

SMART IPM: INTEGRATING AI, IOT, AND REMOTE SENSING FOR REAL-TIME PRECISION PEST MONITORING AND DECISION SUPPORT

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ABSTRACT

Digital innovations are transforming Integrated Pest Management (IPM) by enabling precise, data driven, and environmentally responsible pest control. This study presents a comprehensive smart IPM framework that integrates artificial intelligence (AI), Internet of Things (IoT) devices, and remote sensing technologies to enhance pest monitoring, forecasting,and decision-making in real time. The system combines multispectral satellite imagery with in-field data from smart traps and microclimate sensors to monitor pest populations and crophealth indicators. Machine learning algorithms analyze these data streams to identify pest hotspots, model infestation risks, and generate timely, location specific management enabled early detection of pest outbreaks, leading to proactive rather than reactive pest control measures. This not only resulted in better crop protection and yield stability but also promoted sustainable practices aligned with climate-smart agriculture. By integrating cutting-edge technology with ecological understanding, smart IPM empowers farmers, extension agents,and policymakers to make informed, sustainable pest management decisions, and underscores the potential of digital agriculture to scale precision IPM solutions and reduce agriculture's environmental footprint in the face of evolving pest dynamics and climate challenges.

Keywords: Precision agriculture, smart farming, artificial intelligence, remote sensing, pest forecasting, decision support systems

PHYTO-RHIZOSPHERE INTERCEPTION FOR NEMATODE EXCLUSION (P.R.I.N.E.) A LIVING BIO-BARRIER FOR ROOT PEST MANAGEMENT

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ABSTRACT

Phyto-Rhizosphere Interception for Nematode Exclusion (P.R.I.N.E.) introduces a transformative approach to sustainable nematode management by deploying a perimeter of genetically selected "interceptor plants" as a living, self-sustaining bio-barrier. This system specifically targets sedentary endoparasitic nematodes e.g., Meloidogyne spp. through a "lure and trap" mechanism. Interceptor plants are engineered to exude root-specific biochemical cues that mimic vulnerable hosts, acting as potent chemo-attractants to divert nematodes from primary crops. Upon root penetration, a rapid hypersensitive response is triggered within interceptor tissues, inducing localized cell death that encapsulates and eliminates juvenile nematodes before they establish feeding sites or reproduce. This method offers significant advantages over conventional strategies. It eliminates reliance on synthetic nematicides, reducing chemical runoff, soil toxicity, and non-target harm to beneficial soil organisms. By leveraging ecological deception rather than chemical toxicity, P.R.I.N.E. circumvents pest resistance development. The system operates continuously throughout the growing season, requiring minimal human intervention once established. Interceptor plants also contribute to soil health—post-harvest, their biomass can be tilled into soil as green manure, releasing natural biofumigants that further suppress nematode populations while improving soil organic matter. Compatible with diverse cropping systems,

P.R.I.N.E. is scalable for both smallholder and industrial farming. It provides an economically viable, eco-friendly solution that aligns with agroecological principles, enhancing crop resilience and supporting biodiversity. Crops protected by P.R.I.N.E. also offer market advantages as sustainably produced goods, appealing to environmentally conscious consumers. This innovation represents a proactive, systems-based strategy for long-term root pest management.

Keywords: Sustainable agriculture, nematode management, root exudates, bio-barrier, hypersensitive response, agroecology, soil health, green manure, resistance management.

ECOLOGICAL INNOVATIONS FOR SUSTAINABLE PEST MANAGEMENT

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ABSTRACT

India's agriculture has distinct challenges due to its extensive crop diversity, the preponderance of small landholdings, and the existence of diverse agroecological zones. Ecological innovation in pest control offers a lot of promise to make food more secure, help rural economies, and protect the environment. The new developments in sustainable pest control in India on rice, cotton, vegetables, and pulses were seen. It also looks at the ecological, economic, and social aspects of these developments. Significant progress includes the increased use of biopesticides and biological agents like *Bacillus thuringiensis, Trichoderma spp*., *Beauveria bassiana*, neem extracts, and specificity-based natural antagonists. These agents lower the need for synthetic pesticides and lessen their effects on non- target organisms. Changes to crop ecosystems, such as intercropping, trap crops, cover crops, hedgerows, and refuges and to keep predator and parasitoid populations alive in cotton and vegetable systems. Precision agriculture tools, such as AI and drone-based early detection systems for diseases and insect outbreaks in crops like cashew, rice, and cotton, are reducing the time it takes to act and enabling the more effective use of control chemicals. Comparative field trials in bio-intensive pest management, such as those conducted on cowpea in the sub-Himalayan region, demonstrate that while traditional chemical-based methods may occasionally achieve superior pest suppression or crop yield, eco-friendly approaches more effectively conserve natural predators and pose diminished risks to human health and the environment. An economic study reveals that ecological systems exhibit better cost-benefit ratios, particularly when considering factors such as health hazards, environmental damage, and waste. Challenges to adoption include the diversity of small farms, insufficient farmer education or extension assistance, regulatory and market access difficulties for biopesticides, and the initial capital required for monitoring and data systems. Ecological innovation has significant potential for sustainable pest control in India; the integration of biological, cultural, and technological approaches may provide resilient, productive, and ecologically sustainable agricultural systems.

Keywords: Ecology, predator, parasitoid, sustainable agriculture

HARNESSING THE BLACK SOLDIER FLY (*Hermetia illucens*) FOR SUSTAINABLE WASTE-TO-WEALTH CONVERSION

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ABSTRACT

Organic waste, particularly food and fruit/vegetable residues, imposes a significant environmental as well as economic burden in urban and agriculture systems. The larvae of the black soldier fly, *Hermetia illucens*, provide a potentially interesting bioconversion process to convert these organic wastes into two valuable materials (insect biomass as animal feed and residual frass as an organic fertilizer). In this review/study, we consider the efficiency and positive and negative aspects of food wastes - fruit waste converting into feed and manure by means of black soldier fly larvae (BSFL). The latter reduces the input weight of 60–85 %, depending on kind of substrate and larval density as well as process conditions. The larvae produced are high in protein and lipids, which make them effective as a supplement or partial replacement in aquaculture, poultry and livestock feed. In the meantime, frass as a by-product contains plenty of macro/micro-nutrients (NPK etc.) and could be used to enhance soil properties, however management of its stability, moisture content and maturity is necessary. Key challenges are substrate heterogeneity, moisture balance, process scale-up, separation and sanitization costs, and regulatory acceptance. Life cycle assessments indicate that when operating under ideal conditions the CO_2 intensity and resource use associated with bioconversion using BSFL can be lower than disposal into alternative methods of waste treatment. It therefore stands out as a promising technology within circularity of organic waste, connecting waste valorization to sustainable feed and fertilizer production—assuming operational, economic and regulatory barriers can be tackled.

Keywords: Black soldier fly, *Hermetia illucens, waste conversion, manure*

EVALUATION OF BIO-INTENSIVE IPM MODULES FOR MANAGEMENT OF INSECT-PEST–PATHOGEN COMPLEX IN BHENDI ECOSYSTEM

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ABSTRACT

Bhendi (*Abelmoschus esculentus* L. Moench) is a high-value vegetable crop widely cultivated in South India, but its productivity is severely constrained by the simultaneous occurrence of major insect pests such as the shoot and fruit borer (*Earias vittella*), jassids (*Amrasca biguttula biguttula*), and whiteflies (*Bemisia tabaci*), along with diseases including yellow vein mosaic virus (YVMV) and Fusarium wilt. Over-reliance on chemical pesticides has resulted in pest resurgence, resistance, and residue hazards. Hence, the present study was undertaken during 2024–2025 in Chengalpattu District to develop an eco- friendly, sustainable management strategy. A field experiment was conducted in a Randomized Block Design (RBD) with six bio-intensive IPM modules and a chemical control check. The modules integrated the use of neem-based formulations, *Beauveria bassiana* and *Trichogramma chilonis* releases, soil application of *Trichoderma harzianum*, intercropping with marigold, and yellow sticky traps. Observations were recorded on pest and disease incidence, yield parameters, and cost-benefit ratio. Preliminary results indicated that the module combining neem oil (3%), *B. bassiana* sprays, and *T. harzianum* soil treatment significantly reduced pest and disease incidence while improving marketable yield by 28.4% over control. The bio-intensive modules also promoted natural enemy abundance and reduced chemical dependency. This study demonstrates the potential of bio-intensive IPM as a viable alternative to synthetic pesticides, contributing to safer produce, environmental sustainability, and enhanced livelihood security for bhendi growers in Tamil Nadu's irrigated ecosystems.

Keywords: Bhendi, *Trichoderma harzianum*, Fusarium wilt, IPM, *Beauveria bassiana*

ECO-FRIENDLY IPM STRATEGIES FOR MAJOR PESTS OF OKRA

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ABSTRACT

One of the most widely grown annual vegetable crops grown from seed in India and other tropical and subtropical regions of the world is okra (*Abelmoschus esculentus*), also known as lady's finger and locally called "Bhendi" or "Dherosh." Numerous insect pests target the crop, but the fruit and shoot borer (*Earias spp.*) is the most damaging, resulting in significant damage and production losses of up to 40–50%. Environmental risks, pest resistance, and the extinction of beneficial creatures have resulted from an over-reliance on chemical pesticides for pest management. As a result, in India's agricultural systems, implementing a sustainable Integrated Pest Management (IPM) approach has grown in significance. IPM provides a comprehensive and environmentally responsible strategy by combining several strategies, including the application of resistant cultivars, seed treatment, and successful cultural practices like intercropping, crop rotation, and field sanitation. The use of botanicals or less-toxic pesticides like neem oil and neem seed kernel extract (NSKE), the installation of pheromone traps for pest monitoring, and biological control with natural enemies are important elements of this strategy. In order to promote sustainable pest management and increase okra productivity, farmers must participate in extensive extension activities, demonstrations, and awareness programs in order to guarantee the widespread adoption of IPM.

Keywords: Fruit and shoot borer, okra, Integrated Pest Management (IPM), resistant cultivars, neem oil, NSKE, biological management, fruit and shoot borer, and environmentally friendly pest control

STUDY ON PHYSICO-BIOCHEMICAL ATTRIBUTES OF BRINJAL INFLUENCING RESISTANCE TO SHOOT AND FRUIT BORER *Leucinodes orbonalis* GUENEE

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ABSTRACT

An experiment was carried out with six parents and thirty hybrids of brinjal at Tamil Nadu Agricultural University, Coimbatore to find the influence of biophysical and biochemical characters of brinjal on the infestation to shoot and fruit borer. Among the hybrids Sevathampatti local x Spiny local and Sevathampatti local x Seetipulam local was found least attacked by the borers recording minimum percentage of fruit infestation (14.68 percent) with maximum yield per plant of 3.27 kg per plant. Fruit infestation was positively but not significantly correlated with length of calyx (r = 0.314) whereas, yield per plant (r= -0.297), solasodine (r = -0.170) and phenol (r = -0.572) showed significantly negative correlation with fruit infestation and positive correlation with shoot infestation (r = 0.041), polyphenol oxidase (r = 0.011) and total sugars (r = 0.072). The cross Manaparai local x Spiny local, Sevathampatti local x Spiny local and Sevathampatti local x Seetipulam local recording maximum yield, less shoot and fruit infestation, lowest calyx length, low sugar, high polyphenol oxidase and high phenol could be used as resistant cultivar for further shoot and fruit borer resistance breeding programme.

Key words: Biophysical, biochemical, *Leucinodes orbonalis*, resistance

BIOEFFICACY OF NOVEL INSECTICIDES AGAINST BANANA SCARRING BEETLE *Basilepta subcostata* JACOBY THROUGH LABORATORY BIOASSAY

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ABSTRACT

The banana scarring beetle, *Basilepta subcostata* (Jacoby), is a significant pest distributed across major banana-growing regions of India, with historical reports identifying it as a major pest in multiple states including Bihar, Assam, Uttar Pradesh, and West Bengal. It causes substantial economic losses through foliar and fruit damage. To identify effective control strategies, laboratory bioassays were conducted to evaluate the bioefficacy of thirteen insecticidal formulations against adult beetles. Adult mortality and foliar damage were assessed at 4, 6, and 12 hours after treatment (HAT) using a leaf-dip method. Results indicated that Thiamethoxam 25% WG and Fipronil 5% SC were the most effective treatments, achieving 100% mortality across all time intervals and exhibiting the lowest cumulative leaf damage (1.67% and 2.23%, respectively). Imidacloprid 17.80% SL, Chlorpyriphos 20% EC, and Fipronil 0.3% G also demonstrated high efficacy, with mean mortality rates exceeding 95%. In contrast, Azadirachtin 0.03% and Chlorantraniliprole 0.4% G were the least effective, showing the lowest mortality and highest leaf damage among all treatments. Probit analysis of the top-performing insecticides revealed that Thiamethoxam25% WG had the lowest LC_{50} value (0.103 ppm) and the steepest dose-response slope, confirming its superior toxicity. The study identifies highly effective chemical and botanical insecticides for the sustainable management of *B.subcostata* in banana cultivation systems.

Keywords: *Basilepta subcostata*, Banana scarring beetle, Insecticide efficacy, Probit analysis, Pest management.

LESS EXPENSIVE, DIY METHOD IN REFLECTED LIGHT MICROSCOPY TO DOCUMENT INSECTS: CONCEPTS AND PROCEDURES

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ABSTRACT

The practice of microscopy has been around since the sixteenth century. The field of microscopy has advanced significantly in recent years. Starting with a basic microscope, there are now many different methods, including as electron microscopy, fluorescence microscopy, reflected light microscopy, phase contrast, differential interference contrast, stereo microscopy, and epi lighting. Despite the extreme magnification and high resolution images that electron microscopy provide, we were unable to see the specimen's actual colors. Every type of microscopy requires the sample to be fixed. Delicate structures become crushed, fractured, or deformed as a result. A third eye for seeing the precise morphology of the structures is provided by reflected light microscopy with focus stacking and stitching. More significantly, in contrast to electron microscopy, the sample's original color pattern may be recorded. There are several well-known brands of metallurgical and reflected light microscopes. I'll be talking about the principles and methods of reflected light microscopy. However, not many researchers can afford them due to their high cost. However, they are very expensive and not possible to afford by all the researchers. The DIY technique discussed in my presentation may be useful to amateur photographer, insect enthusiasts and entomologists to photo document insects with less expensive equipment and resulting in a comparably high quality images as that of a standard stereo microscope. The work procedure will be explained with video.

Keywords: Reflected light microscopy, insects, DIY, Concepts and procedures.

OIL BASED FORMULATION OF *Metarhizium anisopliae* (METCHNIKOFF) SOROKIN AGAINST *Helicoverpa armigera* (LEPIDOPTERA: NOCTUIDAE), *Plutella xylostella* (LEPIDOPTERA: PLUTELLIDAE) AND *Spodoptera frugiperda* (LEPIDOPTERA: NOCTUIDAE)

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ABSTRACT

Effective biopesticide formulations are crucial for field-level pest management, ensuring enhanced stability, targeted delivery, and prolonged efficacy under diverse environmental conditions. This study developed and evaluated oil-based formulations of Metarhizium anisopliae (TNAU-MA- GDU) for their efficacy against key pests, Helicoverpa armigera, *Plutella xylostella,* and *Spodoptera frugiperda,* under laboratory conditions. It also optimized culture media for large-scale conidial production and assessed the physico-chemical properties and safety of the formulations. Potato dextrose agar (PDA) was the most effective medium, achieving a radial growth of 81.30 mm and a conidial yield of 2.16×10^8 spores mL^{-1}. Sabouraud maltose agar with yeast (SMA+Y) and Sabouraud dextrose agar with yeast(SDA+Y) also supported significant growth (65.60 mm and 60.60 mm) and yields of 1.16×10^8 and 1.02×10^8 spores mL^{-1}, respectively, suitable for industrial production. Compatibility tests identified sunflower, soybean, mineral, corn, castor, and palm oils as viable carriers at 2–10%concentrations, with palm oil excelling at 10%, yielding a colony diameter of 81.00 mm and 1.61×10^8 spores mL^{-1}. Skimmed milk and ascorbic acid were optimal UV protectants, preserving 65.33% and 64.67% spore germination after 90 minutes of UV exposure at 5% concentration. Emulsifiable concentrate (EC) and oil dispersion (OD) formulations were developed,with OD showing superior spore viability (86.33% and 85.33% germination on sterile and media-coated slides). Both formulations maintained stability across real-time, refrigerated, and accelerated storage, with OD retaining 168.67×10^8 CFU mL^{-1} after 28 days under ambient conditions. At 119 days, OD exhibited the highest viability (83.66×10^8CFU mL^{-1}) compared to EC, wettable powder (WP), and crude suspensions. Pathogenicity assays confirmed OD's superior efficacy, with the lowest LC_{50} (1.56×10^3 to 3.16×10^5 spores mL^{-1}) and LT_{50} (94.53–147.33 hours) across pest instars. Safety assessments showed minimal impact on parasitoids *Telenomus remus* and *Trichogramma pretiosum* (>83% emergence) and moderate effects on predator *Chrysoperla zastrowi sillemi* (survival, pupation, and emergence

59%, 81%, and 81% respectively). The OD formulation's exceptional stability, efficacy, and safety highlight its potential as a robust biopesticide for sustainable field-level pest management.

Keywords : *Metarhizium anisopliae*, UV protectants, oil dispersion

ENTOMOPATHOGENIC POTENTIAL OF SOIL-ISOLATED ENTOMOPATHOGENIC FUNGI *Metarhizium robertsii* STRAIN TNAU ENTMR GYU 1 AGAINST ASH WEEVIL (*Myllocerus subfasciatus*)

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ABSTRACT

The ash weevil *Myllocerus subfasciatus* Guérin-Méneville (Curculionidae;Coleoptera) poses a significant threat to various crops, particularly in tropical and subtropical regions. The adults are foliage feeders and grub feeds on the roots making them difficult to manage. In search of sustainable and eco- friendly management options, the present study focused on the isolation and characterization of the entomopathogenic fungus Metarhizium robertsii (J.F. Bisch., Rehner & Humber) from rhizospheric soil and evaluated its pathogenic potential against *M. subfasciatus.* Soil samples were collected from different districts of Tamil Nadu, Kerala and Karnataka. The fungal isolates were obtained using the insect bait method with *Galleria mellonella* (Linnaeus) (Pyralidae; Lepidoptera) larvae. The results of isolates through morphological identification confirmed Metarhizium spp. The colony was white in colour on vegetative phase and dark green on reproductive phase. Molecular identification was performed using ITS-rDNA sequencing, and BLAST analysis confirmed the identity as *M.anisopliae*. The isolates were submitted in NCBI database and got the accession numbers. Bioassays conducted under laboratory conditions demonstrated significant pathogenicity of the isolate against second instar ash weevil grubs, with mortality rates exceeding 50% within 7-9 days post-inoculation. The sporulation and virulence were studied through SEM and ultramicroscopic studies. TNAU ENTMR GYU 1 demonstrated superior efficacy with lowest LC50 of 2.13x10 6 conidia/ml respectively in the second instar grub of *M. subfasciatus.* The lethal time (LT_{50}) values were 7.04 days calculated to assess virulence. The findings suggest that among the isolates the M. anisopliae TNAU ENTMR GYU 1 possesses promising biocontrol potential and could serve as an effective component in integrated pest management (IPM) strategies for ash weevil control. Further field validation and formulation development are recommended to facilitate its practical application.

Keywords: Ash weevil, TNAU ENTMR GYU 1, *M. robertsii*, histopathology, SEM

EVALUATING APHID RESISTANCE IN BREAD WHEAT *Triticum aestivum* L. GENOTYPES UNDER FIELD AND GROWTH CHAMBER CONDITIONS

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ABSTRACT

Aphids (*Sitobion avenae, Rhopalosiphum padi, and Schizaphis graminum*)are emerging as a serious threat to wheat production in India, with the potential to significantly reduce future crop productivity. To address this challenge, 400 bread wheat genotypes were evaluated for aphid resistance undernatural field conditions during the Rabi seasons of 2023-24 and 2024-25, as well as under growth chamber conditions during Rabi season of 2024-25 at Dr. Rajendra Prasad Central Agricultural University, Pusa. The study employed the Aphid Resistance Index (ARI) scored on a 5-point scale. The evaluation revealed substantial variation in resistance levels among genotypes. Based on ARI scores, 82 genotypes were categorized as highly susceptible (21 or more aphids/plant), 283 genotypes as susceptible (11 to20 aphids/plant) and 55 genotypes as moderately resistant (6 to 10aphids/plant). No genotypes demonstrated immunity (0 aphids/plant) or resistance (1 to 5 aphids/plant). These findings highlight promising wheat genotypes with partial resistance to aphids, which can serve as valuable genetic resources for breeding programs aimed at enhancing aphidresistance and sustaining wheat productivity under field conditions.

Keywords: Wheat, *Sitobion avenae, Rhopalosiphum padi, Schizaphis graminum*, Aphid Resistance

GENOMIC INSIGHTS INTO THE ANTIFUNGAL AND PLANT GROWTH PROMOTING TRAITS OF *Pseudomonas plecoglossicida* NAN2 ISOLATED FROM THE RICE RHIZOSPHERE

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ABSTRACT

Plant growth promoting rhizobacteria (PGPRs) are beneficial microorganisms that inhabit the rhizosphere and enhance plant growth through various mechanisms. In this study, a PGPR strain designated NAN2 was isolated from the rice rhizosphere and demonstrated multiple plant growth promoting traits, including the production of hydrogen cyanide (HCN), ammonia, indole-3-acetic acid (IAA), phosphate solubilization and antifungal activity against *Magnaporthe oryzae*. Complete genome sequencing and annotation of strain NAN2 revealed a genome size of 5356785 basepairs (bp)with a GC content of 62 %, comprising 227 contigs, 4807 coding sequences (CDSs) and a total of 4960 genes. Notably, the genome contains a nonribosomal peptide synthetase (NRPS) gene cluster associated with the biosynthesis of rhizomides (A, B and C). These results suggest that NAN2 has strong potential as an environmentally resilient biocontrol agent that can protect plants from invasive diseases. To our knowledge, this is the first genomic analysis of *Pseudomonas plecoglossicida* NAN2 isolated from rice fields, providing valuable insights into its biocontrol capabilities and plant growth promoting (PGP) properties.

Keywords: Antifungal, Plant Growth Promoting, Traits *Pseudomonas Plecoglossicida,* Nan2, Rice, Rhizosphere

FRUIT FLY DIVERSITY AND RESISTANCE SCREENING IN MANGO AND CUSTARD APPLE CULTIVARS OF RAYALASEEMA FOR SUSTAINABLE PEST MANAGEMENT

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ABSTRACT

The study to document fruit fly species diversity in different fruit crops and their sources of resistance were carried out at College of Horticulture, Anantharajupeta during the years 2023-2024. Fruit fly infested fruit samples of mango and custard apple collected through survey from farmer fields of Ananthapuramu, Chittoor, Nandyal and Annamayya districts of the Rayalaseema region and reared in the laboratory. A total of 15 mango varieties were evaluated under field conditions to assess their susceptibility to fruit fly infestation. Among these, four varieties Jahangir×Khader,Neelum,Prabhashankar and Suvarnarekha were classified as moderately resistant, exhibiting infestation levels ranging from 21% to 50%. Ten varieties Bangalora,Neelum, Baneshan, Yeramanda, Ali Pasand, Neeleshan, Royal Special, Pulihora, Proddutur Avakay and Peether were categorized as susceptible, with infestation levels between 51% and75%. Notably, Dashaheri recorded the highest infestation rate at 75.21%, indicating it as the most preferred variety by fruit flies. Similarly, in custard apple, three varieties Atemoya ×Washington, Yengalampalli No.13 and Rayadurg were found to be resistant, with infestation levels between 11% and 20%. Nine cultivars Pythota-5, Arka Sahan, APK-1, Pythota-1, CRIDA,Pythota-3, Jamdugumpala No.7, Sinhan Local and Molkalnur-8 were moderately resistant(21%–50%), while three varieties Balanagar, NMk-Gold and Pythota-2 were classified as susceptible (51%–75%). Importantly, none of the tested mango or custard apple varieties exhibited complete resistance to fruit fly infestation. These findings reflect the natural host preference of fruit flies observed under field conditions.

Keywords: Fruit fly, Mango, Custard apple, Screening, Varrieties.

ADVANCEMENTS IN ECOLOGICAL ENGINEERING FOR INSECT PEST CONTROL

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ABSTRACT

In agriculture, sustainable pest management is essential because of rising chemical resistance, harm to the environment, and worries about human health. Using ecological innovations that use biodiversity, natural processes, and new technology may help control pests while causing the least amount of harm. Some of the strategies include Integrated Pest Management (IPM), biological management using beneficial insects, entomopathogens, and habitat alteration methods including companion planting, trap cropping, and polyculture. The Sterile Insect Technique (SIT), biofumigation, biosolarization, and smart monitoring utilising IoT sensors or computer vision are all examples of advanced techniques that have even more potential. Case studies—from smallholder farms in Africa using push-pull systems and biopesticides to rice farmers in South-east Asia using adaptive networks— show how important it is to adapt to the local environment, get stakeholders involved, and provide socio-economic incentives. Ecological pest control protects ecosystem services, soil health, and biodiversity. It also helps the economy by lowering input costs and increasing yields over time. The conclusions stress the need for policies that work together, research that involves everyone, and investments that make farming techniques fit with how nature works for long-term sustainability.

Keywords: Sustainable pest management; ecological innovations; Integrated Pest Management; biological control; habitat manipulation; precision monitoring; ecosystem services; yield stability; environmental sustainability

ECOLOGICAL INNOVATIONS IN PEST MANAGEMENT: ENTOMOLOGICAL PATHWAYS TO SUSTAINABLE AGRICULTURE

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ABSTRACT

Agricultural sustainability requires pest management approaches that harmonize productivity with ecological balance. Harnessing nature through entomological innovations offers eco-friendly alternatives to chemical-intensive practices. Beneficial insects provide vital services as pollinators, predators, parasitoids, decomposers, and bioindicators, while strategies such as Integrated Pest Management (IPM), conservation biocontrol, pheromone-based monitoring, and biopesticides strengthen natural regulation of pests. Recent advances in genetic tools, insect farming, remote sensing, and artificial intelligence further expand opportunities for precision and resilience in pest control. Although barriers such as limited awareness, high initial costs, and climate change impacts remain, ecological pest management presents a transformative pathway to safeguard food security, enhance biodiversity, and promote sustainable farming systems.

Keywords: Sustainable agriculture, Integrated pest management, Artificial intelligence.

ECOLOGICAL PEST MANAGEMENT: INSECTS AS CATALYSTS FOR SUSTAINABLE AGRICULTURE

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ABSTRACT

Sustainable agriculture increasingly depends on ecological innovations that harness the natural roles of insects to reduce reliance on synthetic pesticides and safeguard ecosystem health. Insects serve as pollinators, biological control agents, decomposers, bioindicators, and even alternative protein sources, making them indispensable to resilient farming systems. This paper highlights nature-based pest management strategies such as Integrated Pest Management (IPM), conservation of natural enemies, habitat manipulation, and the use of pheromone traps and biopesticides. Emerging tools— including genetic approaches, sterile insect techniques, and AI-based monitoring—further enhance the ecological regulation of pests while minimizing environmental harm. Despite challenges such as knowledge gaps, economic constraints, and climate-induced shifts in pest dynamics, integrating entomological innovations into agricultural practices provides a pathway toward balanced productivity, biodiversity conservation, and long-term food security. By harnessing nature's own mechanisms, ecological pest management fosters a sustainable future for agriculture that aligns productivity with environmental stewardship.

Keywords: Sustainable agriculture, Integrated pest management, AI based techonology.

ECOLOGICAL INNOVATIONS FOR SUSTAINABLE PEST MANAGEMENT IN BHENDI

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ABSTRACT

Bhendi (*Abelmoschus esculentus*) is severely impacted by pests like shoot & fruit borer (*Earias spp.),* whitefly, leafhoppers, aphids and mites, which lower both yield and fruit quality. Reliance on chemical insecticides has led to resistance, environmental harm, residue issues and loss of beneficial organisms. Recent ecological innovations offer sustainable alternatives: Integrated Pest Management (IPM) approaches tailored for bhendi combine regular monitoring, threshold-based interventions, and use of biocontrol agents (parasitoids, predators) to reduce dependence on chemicals. Botanicals and biopesticides (e.g. *Bacillus thuringiensis*, *azadirachtin*, neem products, Spinosad) have shown strong reductions in both shoot and fruit infestation, sometimes exceeding 50–80% lower pest load, with improved economic returns. Cultural practices such as intercropping with non-host or repellent plants, use of trap/border crops, removal and destruction of infested shoots/fruits, conservation or augmentation of natural enemies, and varietal selection for partial resistance also contribute significantly to pest suppression. Some IPM modules have demonstrated not only lower pest incidence but also higher yield and benefit-cost ratios compared to conventional pesticide-heavy regimes. Challenges remain: availability of resistant varieties suited to local conditions, consistency and efficacy of biocontrol under field conditions, farmer awareness, labor and cost for monitoring and implementing IPM components, and supportive policy/regulatory frameworks. Nonetheless, the confluence of cultural, biological, and technological innovations provides a pathway for sustainable pest management in bhendi ensuring stable, high yields, reduced environmental footprint, safer produce, and improved livelihood resilience for farmers.

Keywords: Bhendi, Biocontrol, IPM, Sustainable agriculture, Natural Enemies, Pest outbreak.

ECO-FRIENDLY AND CLIMATE-SMART STRATEGIES FOR MANAGING COFFEE BERRY BORER IN ANDHRA PRADESH

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ABSTRACT

The coffee berry borer (*Hypothenemus hampei*), a globally recognized pest of coffee, has recently emerged in Andhra Pradesh, with infestations first reported in the Alluri Sitarama Raju district's Araku Valley and already spreading from 80 to 140 acres within weeks. This development poses a critical threat to more than 2.5 lakh acres of coffee plantations and the livelihoods of 2.45 lakh tribal farmers in the region. Given the pest's cryptic lifecycle inside coffee berries, conventional chemical control measures remain largely ineffective, making eco-friendly strategies the cornerstone of sustainable management. Ecological innovations such as shade tree regulation, berry sanitation, maintenance of on- farm biodiversity and the use of biological control agents like Beauveria bassiana can provide effective, environmentally safe suppression. Coupled with climate-smart practices that integrate weather-based forewarning models, soil health management and adaptive cultural operations, these approaches enhance resilience under changing climatic conditions. Moreover, incorporating digital tools for pest surveillance and farmer advisories can complement ecological interventions, enabling timely and precise responses. Addressing such emerging pest challenges requires fostering multidisciplinary collaboration among researchers, extension agents, farmers and policymakers to co-develop integrated solutions that are both socially acceptable and ecologically sustainable. The case of the coffee berry borer in Andhra Pradesh underscores the urgent need to harness nature-based innovations, supported by digital and collaborative frameworks, to secure crop protection and safeguard the future of India's coffee sector.

Keywords: Coffee berry borer, Sustainable management, Climate resilience, Biocontrol, Collaboration.

INTEGRATED ECOLOGICAL AND DIGITAL APPROACHES FOR MANAGING TOMATO PINWORM IN TELANGANA

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ABSTRACT

The tomato pinworm (*Keiferia lycopersicella*), a highly invasive pest of tomato, has rapidly emerged as a significant challenge in India, with severe outbreaks reported in Telangana's key tomato-growing districts such as Khammam and Adilabad. Yield losses ranging from 20–30% in open fields to over 70% in polyhouse cultivation have been recorded, threatening farmer incomes and regional vegetable supply chains. Conventional chemical control measures are limited due to the pest's cryptic leaf-mining and fruit-boring behaviour and the risk of resistance development. In this context, eco-friendly strategies form the backbone of sustainable pest suppression. Integrated ecological approaches such as the use of pheromone traps for mass trapping and monitoring, regular destruction of infested plant parts, neem-based botanicals (*Azadirachtin*) and biological control agents like *Trichogramma pretiosum* and Bacillus thuringiensis have shown significant promise. Climate-smart practices, including crop rotation, resistant varieties, and optimized irrigation regimes, enhance resilience, while incorporating weather- based forewarning models can help predict pest outbreaks. Further, digital tools such as mobile-based advisory systems and sensor-assisted pest surveillance can complement ecological interventions, ensuring timely and precise farmer action. The Telangana experience underscores the urgency of harmonizing ecological innovations, digital technologies and climate-smart practices to safeguard tomato production and strengthen sustainable crop protection frameworks across India.

Keywords: Tomato pinworm, Sustainable management, Climate resilience, Biocontrol, Eco-friendly practices

BIOEFFICACY OF NEW SPIROTETRAMAT 150 OD AGAINST APHID *Aphis gossypii* IN BRINJAL

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ABSTRACT

An experiment was conducted to assess the efficacy of spirotetramat 150OD against aphids in brinjal ecosystem. Three doses of spirotetramat 150 OD, viz at 60, 75, 90 g a.i. ha -1 along with two standard checks, Thiamethoxam25WG at 25 g a.i. ha -1 and Dicofol 18.5 EC at 250 g a.i. ha -1 were appraise for their relative efficacy to aphids. After two rounds of application the highest dose of spirotetramat 150 OD at 90 g a.i.ha -1 and 75 g a.i. ha -1 had registered mean reduction of 88.11; 86.72 and 86.28; 85.26 per cent over untreated check in the first and second experiment, respectively on A. gossypii. Thiamethoxam 25 WG at 25 g a.i ha -1 registered mean reduction of 65.64 and 75.10 per cent in aphid's population over untreated check. Based on the results acquired from field studies spirotetramat was found to be effective against *A.gossypii.*

Key words: Spirotetramat, brinjal, aphids, efficacy and brinjal

ADVANCES IN INTEGRATED PEST MANAGEMENT OF SAN JOSE SCALE IN MULBERRY: SYNERGISTIC ROLE OF BIOPESTICIDES, PREDATORS, AND CULTURAL PRACTICES

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ABSTRACT

San Jose scale (*Quadraspidiotus perniciosus* Comstock) is an economically important pest of mulberry, reducing leaf yield and quality essential for silkworm rearing. To overcome limitations of chemical control, the present research at SRM College of Agricultural Sciences, Baburayenpettai, was conducted on mulberry variety Victory1 and Genotype 4. The study aimed to evaluate advances in integrated pest management (IPM) with a focus on the synergistic role of biopesticides, predators, and cultural practices. Field trials compared the response of Victory1 and Genotype 4 under Integrated Pest Management modules involving neem oil, pungam oil, and fish oil rosin soap sprays, integrated with natural predators (*Chilocorus nigritus* (Fabricius), *Cryptolaemus montrouzieri* (Mulsant)) and parasitoids (*Aphytis melinus*), along with pruning and cultural practices. Results demonstrated that both Victory1 and Genotype 4 recorded significant reduction in pest incidence (65–82%) under Integrated Pest Management modules, though Genotype 4 exhibited comparatively higher tolerance to infestation. Biopesticide–predator combinations produced a synergistic effect, while cultural practices minimized reinfestation. Leaf yield and quality improved notably in Victory1 under IPM, ensuring better feed for silkworm rearing. Economic analysis revealed higher benefit–cost ratios in both varieties under IPM compared to conventional management. The findings highlight that integrating eco-friendly IPM strategies tailored for mulberry varieties like Victory1 and Genotype 4 can sustainably suppress San Jose scale, support mulberry leaf productivity and align with climate-resilient practices.

Keywords: Mulberry, San Jose scale, Biopesticides, Predators, Cultural practices

SMART HORTICULTURAL PRODUCTION – A NOVEL APPROACH

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ABSTRACT

In the realm of intelligent agriculture, the concept of smart horticulture production has been gaining traction. It is revolutionizing the agriculture industry by incorporating advanced technologies to increase efficiency and productivity. From automated irrigation systems to drones for monitoring crops, the possibilities are endless. However, the current horticulture production and quality levels are not sufficient to meet the demands of a growing population, climate change, a decrease in the labour force, and a lack of automation. To fully embrace smart horticulture production, need to invest in cutting-edge technologies such as sensors, drones, and automated machinery. Artificial intelligence, big data, the Internet of Things, and cloud computing can provide valuable data and insights to optimize crop production for sustainable growth. With the integration of smart technologies, farmers can remotely monitor soil moisture levels, detect pest infestations early, and adjust irrigation schedules accordingly. This level of precision allows for more sustainable and efficient farming practices. Over the next 30 years, it is anticipated that the industry will evolve towards a smart industry, utilizing mechanical, automated, and information-based processes for production. Smart horticulture production is transforming the way we grow crops. By harnessing the power of technology, farmers can improve yields, conserve resources, and ultimately, feed a growing population. The future of agriculture is smart, and the possibilities are endless.

Keywords: Sustainable pest management, Smart agriculture, Artificial intelligence.

ROLE OF CROP DIVERSIFICATION IN REDUCING PEST OUTBREAKS IN CEREAL-BASED CROPPING SYSTEMS

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ABSTRACT

Crop diversification is an ecologically sustainable approach to pest management that enhances the stability and resilience of cereal-based agroecosystems. Monocropping systems, which dominate modern agriculture, often lead to pest outbreaks due to the continuous availability of host plants and the disruption of natural enemy habitats. In contrast, diversified cropping systems through intercropping, crop rotation, relay cropping, and the inclusion of legumes or cover crops promote ecological balance and suppress pest populations by disrupting pest life cycles and enhancing biological control. The increased plant diversity modifies microclimatic conditions, alters pest colonization behavior, and supports a wider range of predators and parasitoids. Furthermore, diversified systems improve soil health and microbial activity, which indirectly contributes to pest resistance and crop vigor. Empirical studies in rice–wheat and maize sorghum systems have shown that crop diversification can significantly reduce the incidence of major insect pests such as stem borers, aphids, and leafhoppers, while improving yield stability and ecosystem services. Therefore, integrating crop diversification within cereal-based farming not only reduces the dependency on chemical pesticides but also strengthens the ecological integrity of agricultural landscapes. The present review highlights the mechanisms, benefits, and management strategies of crop diversification as a cornerstone of ecological pest management in sustainable cereal production systems.

Key words: Cropping system, relay cropping, cover crops, diversified cropping system

IPM SIGNIFICANCE IN SAFEGUARDING FRESH WATER RESOURCES

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ABSTRACT

Pesticides contaminate water bodies by running off agricultural land or urban areas and entering the surface water and groundwater. These toxic chemicals can harm aquatic ecosystems, causing oxidative stress in organisms and leading to bioaccumulation through the food chain. This contamination threatens biodiversity and poses risks to human health through the consumption of contaminated fish and water. Integrated Pest Management (IPM) safeguards freshwater resources by significantly reducing the overuse of chemical pesticides that contaminate groundwater. IPM emphasizes preventing pest problems through better crop management practices, such as selecting resilient crop varieties, proper soil health management, and good field hygiene, which lessens the need for chemical intervention. IPM employs a combination of cultural, biological, and physical methods to control pests, and only resorts to targeted chemical use as a last resort. This multi-faceted approach ensures that only necessary, low-risk chemical applications are used, and only when justified by economic thresholds, further limiting water pollution. With advances in digital technology, farmers today can remotely monitor environmental conditions (e.g., temperature, humidity, soil moisture) and detect pests or disease outbreaks at their earliest onset. Drones for crop monitoring and aerial surveillance are transforming the fight against pests across large fields or in inaccessible areas. Water management can be linked to pest incidence. For instance, practices like drip irrigation or planting on raised beds can control weeds and use water more efficiently, thereby reducing the amount of water needed for irrigation and preventing potential pest issues that could lead to more pesticide use. This reduces pesticide runoff and leaching, thereby protecting water quality and promoting healthier ecosystems.

Keywords: Integrated Pest Management, Water Resources, Reduce Pollution, Sustainability

BIO-DIGITAL PEST MANAGEMENT: INTEGRATING LIVING SENSORS (INSECTS, MICROBES) WITH AI NETWORKS

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ABSTRACT

The rapid escalation of global pest challenges in agriculture has underscored the need for innovative, sustainable and precise management strategies. Even if conventional chemical-based control techniques are short-term successful, they endanger ecosystems, biodiversity and human health in the long run. Bio-Digital Pest Management is a paradigm shift that combines sophisticated artificial intelligence (AI) networks with biological living sensors, including insects, microbial ecosystems and bioengineered creatures to overcome these constraints. Real-time AI- driven analytics can digitize and understand their bio-signals. Predictive pest surveillance, early outbreak detection, and dynamic ecosystem monitoring are made possible by this bio-digital interface with previously unheard-of accuracy. Pest management systems can transition from reactive interventions to proactive, adaptive tactics by integrating biological sensing, Internet of Things (IoT) sensors and machine learning. In addition to increasing pest control effectiveness, this integration lessens reliance on pesticides, promoting ecological resilience and sustainable food production. Additionally, AI-enabled feedback loops enable ongoing learning from biological data streams, resulting in suggestions for farmers and stakeholders that are more context- specific. Scaling the use of biosensors, guaranteeing the reliability of biological data under changing field settings, and resolving ethical issues with bio-digital convergence are still difficult tasks. However, the combination of AI and live sensors could reinterpret pest control as an eco-centric, self- optimizing system, bringing technology development into line with agroecological principles. This multidisciplinary strategy promotes a balance between production, environmental stewardship, and global food security while providing a fresh route to precision agriculture.

Keywords: Bio-Digital Pest Management, biosensors, living sensors, precision agriculture and Resilience

EXPLORATION AND CATALOGING OF BEE-ATTRACTIVE FLORA

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ABSTRACT

Bees play a crucial role in maintaining ecosystem balance and enhancing agricultural productivity through pollination. Understanding the diversity of flora that attracts bees is essential for conserving pollinator populations and improving habitat management. This study focuses on the exploration and cataloging of bee-attractive flora in a selected geographic region, aiming to document the variety of flowering plant species utilized by bees for nectar and pollen foraging. Field surveys were conducted across different habitats, including gardens, grasslands, forest edges, and agricultural zones, during peak flowering seasons. Flowering plant species were identified and recorded alongside bee visitation frequency, time of activity, and floral characteristics such as color, scent, and morphology. The study revealed a high diversity of plant species across families such as Asteraceae, Fabaceae, and Lamiaceae, which consistently attracted various bee taxa, including honeybees (*Apis spp*.), carpenter bees *(Xylocopa spp*.), and solitary bees. Seasonal variation in floral abundance and bee activity was also observed, highlighting the importance of continuous floral resources throughout the year. The findings provide valuable insights for pollinator conservation strategies, especially in designing pollinator- friendly landscapes and promoting native plant species that support bee diversity. The catalog developed through this research serves as a foundational resource for ecologists, conservationists, and agricultural planners aiming to enhance pollination services and biodiversity in both natural and managed ecosystems.

Keywords: Bee-attractive plants, pollinators, floral diversity, foraging behavior, native flora, biodiversity conservation

DEVELOPMENT OF A COMPREHENSIVE FLORAL CALENDAR

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ABSTRACT

A comprehensive floral calendar is a vital tool for understanding the seasonal dynamics of flowering plant species and their availability to pollinators, particularly bees. This study aimed to develop a detailed floral calendar by documenting the phenology of bee-attractive plant species across different seasons in a selected region. Field surveys were conducted monthly over the course of one year to record the flowering patterns, peak blooming periods and abundance of nectar and pollen resources. Data were collected from various habitats, including agricultural fields, forest margins, home gardens, and natural grasslands. Each plant species was identified, and its flowering duration was mapped to create a month- by-month schedule of floral availability. The findings revealed distinct seasonal variations, with the highest diversity of flowering species observed during spring and late summer. Key plant families contributing to year-round bee foraging included Asteraceae, Fabaceae, Lamiaceae, and Malvaceae. The resulting calendar provides a visual representation of continuous floral resources, aiding in habitat management, crop pollination planning, and conservation efforts. It also helps identify floral gaps— periods with limited flower availability—allowing for targeted planting of supplementary species to support pollinators year-round. This comprehensive floral calendar can serve as a practical guide for farmers, ecologists and conservationists to enhance pollinator health and ensure sustainable agricultural productivity.

Keywords: Floral calendar, phenology, pollinators, bee forage, flowering plants, biodiversity conservation

DIGITAL TRACEABILITY SYSTEMS IN POULTRY PRODUCTION USING BLOCK CHAIN

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ABSTRACT

Blockchain technology, built on the principles of decentralization, security, immutability, and smart contracts, is emerging as a powerful digital traceability system in poultry production. Its distributed data structure enables transparent, tamper-proof, and real-time recording of activities across the supply chain. Although challenges such as block size, scalability, latency, security, and privacy remain, blockchain has demonstrated wide potential in diverse sectors including supply chain management, medical records, finance, IoT, and food traceability. In poultry production, blockchain integrated with IoT devices captures data on feed quality, temperature, humidity, and bird health, which is securely stored on decentralized ledgers. This ensures accurate farm-to-fork traceability, enhancing food safety, fraud prevention, and consumer trust. Smart contracts further automate compliance, quality monitoring, and financial transactions, minimizing human error and disputes. Applications in the poultry, egg, and meat industries highlight its promise in rapid recall management, accountability, and sustainable practices. Despite challenges related to technical complexity, high implementation costs, regulatory frameworks, and adoption barriers, blockchain continues to advance rapidly and offers immense potential to transform poultry production. By ensuring transparency, accountability, and quality assurance, blockchain-driven traceability systems can significantly strengthen confidence among stakeholders and consumers.

Keywords: Block chain, Traceability, Poultry Supply Chain, Smart Contracts, Transparency, and Consumer Trust.

DIGITAL POLLINATOR–PEST BALANCE SYSTEMS: AI MODELS THAT OPTIMIZE PEST CONTROL WITHOUT HARMING POLLINATORS

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ABSTRACT

Agriculture today stands at a crossroads, where the urgent need to suppress pest populations collides with the equally critical necessity of conserving pollinators. The tension between these two objectives threatens both food security and ecological stability. The proposed Digital Pollinator–Pest Balance System (DPPBS) offers a transformative solution by integrating artificial intelligence (AI), real-time monitoring, and predictive analytics to manage insect populations in a balanced manner. Using computer vision and deep learning models, the system differentiates between pest and pollinator species with high accuracy, while Internet of Things (IoT) sensors track environmental variables influencing their activity. AI-driven simulations then forecast pest infestation risks alongside pollinator foraging schedules, thereby optimizing the timing and type of interventions. Rather than relying solely on chemical pesticides, the system can recommend targeted biological control agents, eco-friendly formulations, or precision-applied chemicals during pollinator-inactive periods. This minimizes non- target impacts while sustaining pollination services. Moreover, the system incorporates adaptive learning, where continuous field data refine the accuracy of species recognition and predictive thresholds over time. By combining ecological intelligence with digital technology, DPPBS promotes a resilient agricultural framework that enhances yield stability, protects biodiversity, reduces chemical dependency, and strengthens climate- smart farming practices. In essence, this model redefines Integrated Pest Management as a dynamic, pollinator-sensitive strategy, ensuring that food production systems remain both profitable and ecologically sustainable.

Keywords: Pollinator protection, AI-driven pest management, Digital agriculture, Precision ecology, Sustainable food systems.

HARNESSING INSECT BIODIVERSITY FOR SUSTAINABLE CROP PROTECTION

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ABSTRACT

The idea of sustainable pest management has gained more attention in entomology and agricultural sciences. This is due to increasing evidence of pesticide resistance, ecosystem damage, and negative effects on helpful organisms. Many studies show that using chemical pesticides without care disrupts ecological balance, speeds up pest resurgence, and seriously harms pollinators and natural enemies. To address these problems, approaches that utilize natural processes and insect diversity are being promoted widely. Methods like biological control using predators, parasitoids, and entomopathogens; conserving and boosting natural enemies through habitat management; developing botanical and microbial pesticides; and including these in Integrated Pest Management (IPM) systems have shown successful results in various cropping systems. In addition to reducing reliance on synthetic products, these strategies improve essential ecosystem services such as pollination, soil health, and natural pest control. This, in turn, strengthens overall agro-ecosystem resilience. Moreover, combining traditional farming knowledge with modern entomological research offers solutions that are adaptable, environmentally friendly, and economically sound for farming communities. These comprehensive approaches support biodiversity, enhance food security, and promote agriculture that can withstand climate changes. By restoring ecological balance and reducing harm to non-target species, these advancements place entomology at the forefront of sustainable agricultural change. Tapping into nature's potential not only provides a way to control pests effectively but also lays the groundwork for future agricultural development and long-term sustainability.

Keywords: sustainable pest management, ecological innovations, biological control, integrated pest management, insect biodiversity, climate resilience

Momordica cymbalaria LEAF WATER EXTRACTIVES AGAINST THE WRIGGLERS OF *Culex quinquifasiatus* SAY

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ABSTRACT

Mosquitoes are a serious threat to public health as they act as vectors helping on transmitting many diseases that can be morbid and fatal. Mosquito control is the major menace that rely to a maximum on chemical/ synthetic materials which are widely used in public and household areas where it creates a cause for several serious health issues. The effects are eerie as well. We planned a plant-based material for mosquito control and stepped in with a simple fresh water extractive of *Momordica cymbalaria* leaves. Mosquito management using fresh leaf extracts of *M. cymbalaria* against the wrigglers of *Culex quinquifasiatus* was experimented and the effects of the leaves extract on wrigglers and their corresponding sub-lethal and lethal doses were calculated along with their midgut effect on wrigglers. The sub-lethal (LC 50) and lethal (LC 95) concentrations were 1.96 and 4.24 percent. The midgut histology has shown complete loss of columnar cells, and complete break-down of plasma membrane, which shows potential insecticidal properties against mosquitoes.

Keywords: Mosquitoes; *Momordica cymbalaria*; Bio pesticides; Larvicidal; Midgut histology.

DIGITAL FRONTIERS IN IPM: PRECISION MANAGEMENT OF TEA MOSQUITO BUG (*Helopeltis* Spp.) IN CASHEW

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ABSTRACT

The tea mosquito bug (*Helopeltis spp.*) is a major pest in cashew production, causing substantial yield losses of 40–60 per cent by feeding on young shoots, inflorescence and nuts leading to necrosis, nut drop and reduced quality. Conventional management relying on repeated chemical sprays is increasingly unsustainable due to the pest's rapid population growth, cryptic feeding behaviour and associated ecological and health risks. Precision driven Integrated Pest Management (IPM) approaches offer transformative solutions for sustainable control. Digital monitoring tools, including sensor- enabled sticky traps and image-based pest detection systems facilitate real time surveillance of pest populations and hotspot mapping. Decision support systems, integrating predictive analytics with weather based forewarning models enable timely and targeted interventions. Drone assisted application of biopesticides and beneficial natural enemies enhances field level efficiency while reducing labour and chemical inputs. Ecological strategies such as release of egg and nymphal parasitoids, neem based formulations and systematic removal of infested plant parts further strengthen pest suppression. Mobile enabled advisories and farmer focused digital platforms bridge knowledge gaps, promoting adoption of climate smart and environmentally sustainable practices. By integrating technological innovations with ecological principles, cashew protection systems can achieve precision, resilience and long term sustainability.

Keywords: *Helopeltis spp.,* Cashew, Precision IPM, Digital surveillance, Biological control and Climate-smart pest management.

ECOLOGICAL INNOVATIONS FOR SUSTAINABLE MANAGEMENT OF RED PALM WEEVIL *Rhynchophorus ferrugineus* IN COCONUT

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ABSTRACT

The red palm weevil *(Rhynchophorus ferrugineus*), a devastating pest of coconut has emerged as a major threat to coconut production across tropical regions, causing severe damage to palms and yield losses that may exceed 50–60 per cent under favourable conditions. Conventional chemical control strategies are largely constrained by the pest's concealed larval stage within the trunk and fronds, rapid resistance development and associated environmental hazards. Ecological innovations provide promising avenues for sustainable management of this pest. Integrated pest management (IPM) approaches combining pheromone traps for mass trapping and monitoring, mechanical removal of infested tissues and application of botanicals such as neem extracts have demonstrated notable effectiveness. Biological control agents, including entomopathogenic nematodes, fungi and natural predators contribute to eco-friendly regulation of weevil populations. Climate-resilient strategies such as staggered planting, tolerant coconut varieties and regular field sanitation enhance system level sustainability, while predictive models based on weather and phenology enable timely interventions. Digital tools, including mobile based advisories and sensor assisted surveillance further support precision management. By integrating natural processes with climate-smart and digitally enabled strategies, coconut cultivation can transition towards a more resilient and environmentally sustainable pest management paradigm.

Keywords: *Rhynchophorus ferrugineus*, Coconut, Ecological pest management, Integrated Pest Management, Biological control, Climate-smart agriculture.

SOIL MICROBIOME ENGINEERING FOR RESISTANCE AGAINST RICE BROWN PLANTHOPPER (*Nilaparvata lugens*)

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ABSTRACT

The brown planthopper (BPH), *Nilaparvata lugens* is one of the most serious insect pests of rice, causing hopper burn, stunting and transmitting grassy stunt and ragged stunt viruses. Overuse of insecticides has led to resistance development, ecological disruption and resurgence of BPH, necessitating sustainable alternatives. Recent advances in soil microbiome engineering demonstrate its potential as an ecological tool to strengthen plant defenses against BPH. Beneficial microbes such as *Trichoderma harzianum*, Pseudomonas fluorescens, Bacillus subtilis and arbuscular mycorrhizal fungi colonize rice roots and induce systemic resistance by activating jasmonic acid and salicylic acid signaling. This leads to enhanced production of defense enzymes (polyphenol oxidases, peroxidases) and secondary metabolites that deter insect feeding. In addition, microbial volatile organic compounds (VOCs) disrupt BPH probing and oviposition, while certain rhizobacteria enhance silicon uptake, reinforcing plant cell walls. Innovations such as microbial consortia, seed bio-priming and biochar- based inoculants improve the survival and persistence of beneficial microbes under field conditions. Studies have shown that rice plants treated with Trichoderma and Pseudomonas exhibit up to 40–60 per cent reductions in BPH populations along with improved nutrient use efficiency and plant vigor. Metagenomic studies now identify keystone taxa linked to insect resistance, enabling the design of synthetic microbiomes tailored to rice ecosystems. Field evidence further demonstrates that microbiome-based interventions conserve natural enemies and reduce pesticide reliance, making them vital for regenerative rice production. In conclusion, soil microbiome engineering offers a frontier in sustainable pest management by coupling belowground biodiversity with aboveground pest suppression. This ecological approach can minimize insecticide dependence, enhance soil health, and ensure stable rice yields under intensive cultivation systems.

Keywords: Soil microbiome, *Nilaparvata lugens*, induced systemic resistance, beneficial microbes, rice IPM

IOT-ENABLED SMART TRAPS FOR PRECISION SURVEILLANCE OF TOMATO LEAF MINER (*Tuta absoluta*)

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ABSTRACT

The tomato leaf miner (*Tuta absoluta*) is a highly invasive pest causing severe yield losses in tomato cultivation worldwide. Its rapid life cycle, high fecundity and ability to develop resistance to chemical insecticides make timely and accurate pest monitoring essential for effective integrated pest management (IPM). This study focuses on the development and deployment of IoT-enabled smart traps for real time surveillance of T. absoluta. These traps combine species specific pheromone lures with IoT sensors to automatically detect and quantify adult moth populations, transmitting data wirelessly to a centralized platform for continuous monitoring. Advanced data analytics and mapping tools enable farmers and researchers to identify pest hotspots, predict infestation trends and implement targeted interventions with minimal environmental impact. Field trials conducted across multiple tomato growing regions showed that smart traps significantly reduced manual monitoring labour, improved early detection accuracy and supported data driven pest management decisions. By integrating IoT technology with conventional pest control strategies, this approach contributes to sustainable agriculture, reduces economic losses and offers a scalable model for precision pest management applicable to other agricultural pests.

Keywords: *Tuta absoluta*, IoT, smart traps, precision pest management, tomato leaf miner, integrated pest management, real-time monitoring, sustainable agriculture.

BIOCONTROL POTENTIAL OF *Heterorhabditis bacteriophora* (POINAR) AGAINST RHINOCEROS BEETLE, *Oryctes rhinoceros* (L.)

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ABSTRACT

The coconut rhinoceros beetle (CRB), *Oryctes rhinoceros* (L.) (Coleoptera: Scarabaeidae), is a major pest of coconut, causing over 10% yield loss. Adult beetles bore into unopened leaves and inflorescences, while grubs feed on decomposing organic matter in manure pits. In this study, the infectivity of the entomopathogenic nematode (EPN) *Heterorhabditis bacteriophora*, multiplied in black soldier fly larvae (BSFL), *Hermetia illucens* L., was evaluated against all three larval instars of CRB using different concentrations of infective juveniles (IJs). All three instars showed dose-dependent mortality, with no mortality at very low doses (100–300 IJs per insect). In the first and second instars, mortality began within 2–4 days and reached 100% by 6 DAT at 20,000 IJs and by 10 DAT at 10,000 IJs, while lower doses (500–5,000 IJs) caused partial mortality of 28–87% and 33–93%, respectively, by 12 DAT. The third instar was less susceptible, with mortality starting at 6–8 days and reaching only 40% at 20,000 IJs by 12 DAT. A t-test comparing nematodes produced from BSFL and wax moth larvae showed no significant difference in infectivity. These results confirm that H. bacteriophora is highly effective against early instars of CRB. Even though wax moth larvae (*Galleria mellonella*) are effective for nematode multiplication, BSFL offer a simpler, more cost-effective alternative host for multiplication of these nematodes, which act as a valuable tool for integrated pest management.

Keywords: Coconut rhinoceros beetle, EPN, *Heterorhabditis bacteriophora*, black soldier fly larvae

SEMIOCHEMICAL HIGHWAYS: USING PLANT–INSECT CHEMICAL SIGNALS FOR SUSTAINABLE PEST MANAGEMENT

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ABSTRACT

Plants and insects communicate extensively through chemical signals, forming a complex network of semiochemicals that regulate ecological interactions. These signals, often termed semiochemical highways, play a pivotal role in mediating attraction, repulsion, and defense within agricultural ecosystems. Harnessing these natural chemical cues offers a promising alternative to pesticide- dependent pest management, aligning with the goals of sustainable and climate-smart agriculture. Semiochemicals such as pheromones, allomones, kairomones, and synomones can be deployed to manipulate insect behavior—either by disrupting pest mating cycles, repelling herbivores, or enhancing the activity of natural enemies. Advances in chemical ecology, coupled with precision application technologies, now make it feasible to exploit these interactions at the field scale. For instance, pheromone traps and attract-and-kill strategies reduce pest populations without harming pollinators or beneficial arthropods. Similarly, plants can be engineered or selected for enhanced volatile organic compound (VOC) emissions to attract parasitoids and predators, strengthening biological control. Integration of semiochemical strategies with digital agriculture such as remote sensing, AI-based insect monitoring, and automated release systems further enhances efficiency, allowing real-time, adaptive pest management. Unlike synthetic pesticides, semiochemical-based approaches leave minimal residues, reduce resistance development, and maintain ecosystem balance. As agriculture seeks resilient solutions to climate variability and pest adaptation, semiochemical highways provide a biologically grounded, environmentally friendly framework. By turning plant–insect communication into a management tool, we can shift from reactive pest suppression to proactive ecological regulation, ensuring both crop productivity and biodiversity conservation.

Keywords: Semiochemicals, Plant–insect interactions, Sustainable pest management, Chemical ecology, Biological control

TRAPPING TROUBLE: SUSTAINABLE CONTROL OF RHINOCEROS BEETLE IN COCONUT

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ABSTRACT

The Rhinoceros beetle (*Oryctes rhinoceros L.*) is a destructive pest of coconut, damaging unopened fronds and palm crowns, which leads to reduced vigour, yield loss, and in severe cases, plant mortality. Conventional insecticidal control poses environmental and health concerns, highlighting the need for eco-friendly alternatives. In the present study, the effectiveness of bucket traps baited with male aggregation pheromone (Oryctes lure contains ethyl 4-methyloctanoate) was evaluated as a component of Integrated Pest Management (IPM) against *O.rhinoceros*. Traps were installed within plantations at 4-6 traps per acre, monitored regularly, and combined with sanitation practices and biological control agents. The bucket traps effectively mass-trapped adult beetles, with a significant reduction in pest population observed over the cropping season. Integration with field sanitation (removal of decaying organic matter) and entomopathogenic fungi (*Metarhizium anisopliae*) further enhanced control efficiency. Compared with chemical-only treatments, the IPM approach incorporating bucket traps resulted in reduced infestation, healthier palms, and minimized pesticide use. These findings confirm that bucket traps serve as a practical, low-cost, and environmentally safe tool within an IPM framework for sustainable rhinoceros beetle management. Adoption of this strategy can support long-term productivity and ecological balance in coconut ecosystems.

Keywords: Rhinoceros beetle, Bucket traps, Aggregation pheromone, IPM, Biological control.

SYNERGISTIC EFFECTS OF MICROBIAL CONSORTIA IN INTEGRATED PEST MANAGEMENT

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ABSTRACT

Microbial biopesticides have appeared as a promising alternative to synthetically produced chemical pesticides, providing target-specific pest control methods that are environmentally friendly. Although studies have indicated that single strain applications of bacteria, fungi, or viruses have great potential, research is beginning to show the advantages of using microbial consortia. These mixtures contain a variety of organisms that use a variety of compatible mechanisms of action, such as the production of toxins and parasitism, as well as competition and induced systemic resistance to increase pest suppression. Not only do the interactions between these organisms increase efficacy across a wider variety of insects pests and potential diseases, but they also reduce the probability of pests developing resistance. Further, microbial consortia can better adapt to changing environmental conditions, which will help provide longer persistence and stability compared to using a single organism treatment. Developments in both biotechnology and formulation science have also allowed the composition of associated mixtures that can be active, while still maintaining decent shelf life and stability. By introducing these consortia into current pest management practices, we, as a group, can reduce the use of chemical pesticides and promote more sustainable agricultural practices, decrease pesticide impact on soil health, and promote biodiversity. Still challenges exist for the large-scale production or and regulatory approval of multi-microbe biopesticides. Assisting researchers in overcoming these hurdles via permission and policy will encourage researchs further use of microbials; bio pesticidal properties. Thus, the utilization of microbial consortia represents an innovative approach for integrated pest management along with global efforts to achieve food security while minimizing environmental impacts.

Keywords: Microbial consortia, biopesticides, synergistic interactions, integrated pest management, sustainable agriculture, pest resistance.

EVALUATING THE DUAL ACTION EFFICACY OF LEMONGRASS OIL AGAINST *Galleria mellonella*

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ABSTRACT

The greater wax moth, *Galleria mellonella,* is a significant economic pest in apiculture, causing extensive damage to honeybee combs. The reliance on chemical fumigants raises concerns about honey and wax contamination, necessitating the exploration of safe and sustainable alternatives for pest management. This study evaluated the dual action efficacy of *Cymbopogon citratus* oil, a widely available botanical, as both a larvicide and an oviposition repellent against *G. mellonella.* A laboratory study was conducted to assess five treatments, spray emulsions at 2.5%, 5%, and 10%, pure oil vapor treatment and control. Larval mortality and adult oviposition were quantified to establish a dose- response relationship. The results revealed a strong, dose dependent efficacy. The 10% spray achieved 98.0% larval mortality and almost completely inhibited egg-laying. Notably, the pure oil vapor treatment resulted in 99.5% larval mortality and complete repellence, demonstrating the profound potential of fumigation. The 5% concentration also proved highly effective, suggesting a viable threshold for practical control. We conclude that lemongrass oil is a potent biopesticide, and its application as a fumigant presents a highly effective, practical and ecologically sound strategy for beekeepers to protect colonies from wax moth infestation.

Keywords: Greater wax moth, Lemongrass, Botanical Pesticide, Repellent, Fumigant.

HABITAT MANIPULATION STRATEGIES FOR SUSTAINABLE MANAGEMENT OF RUGOSE SPIRALING WHITEFLY *Aleurodicus rugioperculatus* IN COCONUT

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ABSTRACT

Coconut palm (*Cocos nucifera L.*) suffer variety of insect pest infestations, notably the recent invasive rugose spiraling whitefly (RSW), *Aleurodicus rugioperculatus* Martin (Hemiptera: Aleyrodidae), which is an economically significant pest. Further, this pest also coexists with subsequent invasive whitefly species viz., Bondars nesting whitefly, *Paraleyrodes bondari*, nesting whitefly, P. minei and palm infesting whitefly *Aleurotrachelus atratus.* Numerous natural enemies have been documented in association with RSW. Among, the most effective are the parasitoid *Encarsia guadeloupae* Viggiani (Hymenoptera: Aphelinidae) and the predator *Apertochrys aastur* (Banks) (Neuroptera: Chrysopidae). However, their use alone to suppress this whitefly may be difficult under severe outbreak conditions; therefore, integration of compatible biocontrol-based management strategies is ideal to develop state specific protocol. Hence, bio-intensive integrated pest management (BIPM) is considered the desirable path for achieving sustainability and which reduces chemical input costs and on-farm and off-farm environmental impacts. Two BIPM modules and conventional agronomic practices were validated under field condition. Results revealed that BIPM modules-I was found superior in managing RSW, which consists of standard recommended agronomic practices; intercropping with banana; installation of yellow sticky traps @ 30 traps /ha; inundative release of A. astur @ 1000 eggs /ha; inundative release of E. guadeloupae @ 1000 adults /ha and foliar application of *Isaria fumosorosea* @ 5g/L, with the maximum overall pest reduction (75.88- 80.24%). Besides, highest natural parasitism (67.36-81.45%) and population of A. astur (5.89- 6.85 grub/leaf) were maximum in BIPM module-1 than farmers practices and other BIPM modules. Therefore, farmers and other stakeholders were sensitized for extensive promotion of BIPM module to achieve greater adoption for management of RSW in coconut.

Keywords: Invasive whiteflies, Coconut, Habitat manipulation, Cana indica, banana, intercrop

FROM HARASSING NATURE TO HARNESSING NATURE – TOWARDS ECOFRIENDLY PEST MANAGEMENT

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ABSTRACT

The transition *"From Harassing Nature to Harnessing Nature – Towards Ecofriendly Pest Management*" reflects the urgent need to shift human practices from exploitative to sustainable. Over the past decades, the excessive use of synthetic chemicals in agriculture has caused severe ecological imbalance. According to the U.S. FAO Pesticide Use and Trade Report (1990–2020), an average of 30 million tons of pesticides have been dumped into soils globally, leading to soil degradation, contamination of water resources, loss of biodiversity, and adverse effects on human health. These persistent chemicals disrupt soil microbiota, reduce crop productivity, and accumulate in the food chain, posing chronic health hazards. To mitigate these impacts, Integrated Pest Management (IPM) offers an eco-friendly framework combining cultural, mechanical, and biological control methods. Cultural practices such as crop rotation, field sanitation, and resistant varieties reduce pest incidence; mechanical methods like trapping and hand-picking directly remove pests; and biological approaches harness natural enemies like parasitoids, predators, and entomopathogenic microbes. Innovative strategies have further strengthened IPM—such as the use of *Beauveria bassiana* and pheromone trapping for coffee berry borer (*Hypothenemus hampei*) management, and nucleopolyhedrovirus (NPV) and egg parasitoids like *Trichogramma pretiosum* for fall armyworm (*Spodoptera frugiperda*) suppression. These examples illustrate how modern science is aligning with nature's mechanisms, marking the transformation from harming ecosystems to harnessing their resilience for sustainable agricultural development.

Keywords: Sustainable agriculture, Integrated Pest Management (IPM), pesticide pollution, soil contamination, environmental health, coffee berry borer, fall armyworm, ecosystem resilience.

RNAi-BASED BIOPESTICIDE: A TARGETED APPROACH FOR CONTROLLING THE INVASIVE GIANT AFRICAN SNAIL

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ABSTRACT

RNA interference (RNAi) technology holds promise as a biopesticide approach against the invasive giant African snail (*Lissachatina fulica*), targeting genes critical for survival, growth, or reproduction through a highly specific gene-silencing process. The core mechanism involves identifying unique essential genes, designing double-stranded RNA (dsRNA) triggers to match these targets, and encapsulating dsRNA in protective nanoparticles to ensure efficient delivery and stability in the field. Bait formulations facilitate snail uptake and subsequent gene silencing, resulting in mortality if targeted proteins are vital. However, challenges remain in ensuring species specificity, overcoming biological barriers to oral delivery, confirming efficacy in *Lissachatina fulica*, and maintaining dsRNA stability under environmental conditions. Regulatory approval and public acceptance will also be crucial before wide deployment. While laboratory RNAi experiments in other snail species demonstrate potential, more research is needed for scalable, field-ready RNAi-based biopesticides targeting the giant African snail, highlighting their future role as targeted, environmentally friendly alternatives to chemical controls.

Keywords: RNAi, Biopesticide, African snail, Nanoparticles

ECOLOGICAL INNOVATIONS FOR SUSTAINABLE MANAGEMENT OF FRUIT FLY (*Bactrocera cucurbitae*) IN CUCURBITS

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ABSTRACT

The melon fruit fly (*Bactrocera cucurbitae*), a destructive pest of cucurbitaceous vegetables, has emerged as a persistent challenge across major production systems, causing yield losses that may exceed 70 per cent under favourable conditions. Conventional chemical management remains largely ineffective due to the pest's concealed larval feeding within fruits and its high potential for resistance development, while indiscriminate pesticide use further exacerbates ecological and food safety concerns. In this context, ecological innovations are pivotal for sustainable suppression. Integrated pest management (IPM) frameworks incorporating pheromone and cue-lure traps for mass trapping and population monitoring, field sanitation through systematic destruction of infested fruits, and deployment of botanicals such as neem-based formulations have demonstrated significant efficacy. Biological control agents, including parasitoids of fruit fly pupae and entomopathogenic fungi, offer additional avenues for environmentally benign regulation. Climate-resilient strategies such as crop rotation, synchronized sowing, and cultivation of tolerant varieties enhance system-level resilience, while weather-based pest forewarning models can guide proactive interventions. Digital innovations ranging from mobile-enabled advisories to sensor-driven surveillance provide precision support to farmers, bridging ecological approaches with timely decision-making. By harnessing natural processes and embedding them within climate-smart and digitally enabled pest management systems, the cucurbit sector can transition toward a more resilient and sustainable crop protection paradigm.

Keywords: *Bactrocera cucurbitae*, Cucurbits, Ecological pest management, Integrated Pest Management, Biological control and Climate-smart agriculture.

BIO INSPIRED ROBOTIC MODEL (ORNITHOPTERA)

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ABSTRACT

Crop depredation by birds in Agricultural field (Nearly 35 % to 65% of crops are destroyed by crop eating birds like sparrow, pigeon, parrot etc.,) is a serious threat to agriculture sector. Traditional methods of scaring birds away use a lot of resources, which harms the environment and creates problems for farms. Crops are still being damaged, highlighting the need for long-lasting solutions that protect the environment and maintain agricultural production. Therefore farmers need Eco-friendly modern bird scaring technique to save their crops. This innovative device harnesses the power of biomimicry, emulating the flight patterns and predatory behavior of natural avian predators to effectively deter nuisance birds from agricultural fields. It autonomously patrols the skies above fields, creating a dynamic and realistic threat presence that encourages birds to seek safer feeding grounds. With its non-lethal and environmentally friendly approach, the ornithopter offers farmers a sustainable solution to protect crops and minimize bird- related damage, ensuring optimal yields and agricultural productivity. The adoption of bird-inspired strategies represents a crucial advancement in the sustainability and precision of crop protection systems.Biological entity/ process inspired from:The meticulously crafted robotic bird Ornithopter is bio inspired/mimicked, by adopting elements from indigenous birds like falcons, vultures, and eagles. By precisely imitating their look and predatory behaviors, Ornithopter is designed to effectively discourage cropeating birds in agricultural environments. Ornithopter offers an ethical and efficient solution by imitatingnature's techniques, and safeguarding crops while minimizing its adverse impacts on the environment. Analyzing avian predators, constructing an affordable3D-printed framework, and incorporating motors,sensors, and solar panels are all necessary steps in the construction of a Ornithopter prototype. Programming features include autonomous operation, identification of birds, and lifelike wing movements. Field testing determines the success rate with bird repellent,directing successive improvements. Energy efficiency balancing,choosing the right materials,successful bird authentication, and Ornithopter adaptation to various agricultural contexts are among the challenges. To develop a profitable, effective, and resilient concept that safeguards crops while consuming the fewest resources possible while complying with both environmental and agricultural targets, these issues must be addressed.

Keywords: Sustainable agriculture, Integrated pest management, Automated machineries

ECO-FRIENDLY BOTANICALS TREATMENT AND SMART PACKAGING: SUSTAINABLE MANAGEMENT OF *Rhyzopertha dominica* ON STORED WHEAT

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ABSTRACT

The present investigation was undertaken at the Post Graduate Laboratory, Department of Entomology, Junagadh Agricultural University, Junagadh, Gujarat, during 2024–2025 to evaluate the efficacy of different botanicals, inert dusts as seed protectants and packaging materials against the lesser grain borer*, Rhyzopertha dominica* (F.) in stored wheat. The pooled data on adult mortality revealed significant variation among botanicals, with a marked decline in mean adult mortality over time, from 86.11% after one month to 36.84% after nine months. Among the botanicals tested, azadirachtin 1.0 EC @ 1.5 ml/kg seed was most effective, consistently recording the highest adult mortality, followed by neem oil @ 5 ml/kg, neem seed kernel powder @ 5 g/kg and neem dry leaf powder @ 5g/kg. Castor oil and groundnut oil (each @ 5 ml/kg) showed moderate efficacy, while custard apple seed powder, mint leaf powder and talc (each @ 5 g/kg) were least effective. A similar trend was observed across all storage intervals from one to nine months. Population growth studies after nine months further substantiated the superior efficacy of azadirachtin, which was at par with neem oil, while NSK powder and neem dry leaf powder showed intermediate protection. Castor and groundnut oil were statistically at par and the least effective treatments were custard apple seed powder, mint leaf powder and talc, which supported higher pest multiplication, with talc only slightly better than the untreated control. In the evaluation of packaging materials, considerable variation in adult emergence, grain weight loss and protection was observed after nine months. Gunny and cloth bags supported heavy infestation, with the gunny bag showing the highest adult emergence and maximum weight loss. HDPE bags offered superior protection, consistently registering the lowest adult emergence and weight loss due to their impermeable structure, while polypropylene bags performed next best, significantly better than polyethylene, which showed moderate susceptibility. Overall, the study highlights azadirachtin and neem oil as promising botanical protectants and HDPE bags as the most effective packaging material for long-term safe storage of wheat against *R. dominica.*

Keywords: Botanicals, Lesser grain borer, *Rhyzopertha dominica* (F.), Packaging materials, Seed protectant and Wheat

MANAGEMENT OF FRUITFLIES *Bactrocera dorsalis* IN MANGO ECOSYSTEM OF A.P

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ABSTRACT

Fruit flies are considered as most obnoxious pests damaging the crops globally. Fruit flies result in significant damage from 20-40% to fruits and vegetables in field and post harvest scenarios. Among different varieties grown in Andhra Pradesh, Banganapalli, Totapuri are highly popular mango varieties utilised for table and for processing ready to serve juice. But unfortunately these varieties are highly susceptible to fruitfly attack causing huge economic losses to the farmers. During Covid-19 lock down period (2020, 2021 and 2022) there is delay in harvesting mango fruits in Andhra Pradesh leading to multiplication of fruitflies (*Bactrocera dorsalis*). Offseason rains during March, 2023 and April, 2023 coupled with residual fruitfly population due to delayed harvestings during Covid-19 era resulted in severe fruitfly outbreak in mango ecosystem in A.P. Farmers are facing lot of problem due to fruitfly damage in mango which directly affects the final yields. Hence the experiment was planned and initiated during 2022-2023 with 7 treatments at Dr.YSRHU-Mango Research Station, Nuzvid, Andhra Pradesh (16.7876° N, 80.8490° E). Among treatments T 1 was installation of Methyl Eugenol traps which is common among the treatments. Among the different treatments evaluated against the fruitflies Spinosad 45 SC @ 0.35ml/L and Azadirachtin 10,000 ppm@ 1ml/L when sprayed after 30 and 50 days after fruitset were found to be effective in reducing the pest population with minimum damage percentage of 7.3 and 8.3 followed by Decamethrin 0.5ml/L+ Azadirachtin 10000 ppm @ 2ml/L with percent damage of 9.3 compared to the untreated control with 36.3 percent damage. T 1 (Methyl Eugenol traps) alone was not effective in controlling the fruitfly population in mango ecosystem and upto 18.3 percent damage was recorded. Fruitflies trapped in various treatments were recorded at different Standard Meteorological Weeks (SMW). Fruitfly specimens were identified by Dr.David, Entomologist from NBAIR, Bengaluru and confirmed the species as Bactrocera dorsalis (Hendel). There is no significant difference in the oviposition marks observed after the sprayings and there is no significant difference in the fruitflies trapped in the Methyl Eugenol traps installed in various treatments. Hence before harvest and after harvest parameters were taken into consideration and percent damage was recorded. Fruit fly management in mango involves summer ploughing, clean cultivation and

removal and destruction of damaged and fallen fruits below the trees, proper disposal by burning or disposing in deep furrows 50 cm below the ground, Erection of Methyl eugenol traps @ 5/acre, by adjusting harvest timing, especially by harvesting fruits at the green-mature stage or at the yellow-point onset as fruit fly infestation was closely related to changes in the peel texture (firmness, in particular) and chlorophyll fluorescence of the fruit as it ripened and by spraying Spinosad 45 SC @ 0.35ml/L or Azadirachtin 10,000 ppm@ 1ml/L. Management of fruitfly is the need of the hour so that the farmer will be benefitted economically.

Keywords: Management, fruitflies, *Bactrocera dorsalis*, mango

COLD PLASMA SEED TREATMENT: AN INNOVATIVE APPROACH FOR SUSTAINABLE PEST MANAGEMENT IN RICE

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ABSTRACT

Rice (*Oryza sativa* L.) is a globally significant staple crop, but its productivity is often limited by various pest pressures. The growing need for sustainable agriculture calls for new, environmentally friendly ways to reduce pest damage while using fewer chemical pesticides. Cold plasma seed treatment has become a promising non-thermal technology that can make rice more resistant to pests. This method uses ionized gases to make reactive oxygen and nitrogen species (ROS/RNS), which are strong signaling molecules that start stress-responsive and defense-related pathways at the molecular and cellular level. Exposing rice seeds to cold plasma has been demonstrated to enhance germination kinetics, seedling vigor, and early establishment, while also priming defense mechanisms against biotic stresses. Cold plasma treatment can cause changes in the epigenome, such as changes in DNA methylation patterns and histone remodeling. These changes can affect the transcription of important pest-resistance genes. These epigenetic effects could have benefits for future generations, making crops more resistant to pests in the next crop cycle. It is possible to create a sustainable, non-GMO way to control pests that fits with the principles of ecological farming by adding cold plasma seed treatment to rice growing systems.

Keywords: Cold plasma, rice, seed treatment, sustainable pest management, reactive oxygen species, epigenetic priming, eco-friendly crop protection.

Thrips parvispinus KARNY (THYSANOPTERA: THRIPIDAE): AN EMERGING PEST OF CHILLI IN KERALA

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ABSTRACT

Chilli (*Capsicum annuum L.*), an essential commercial vegetable, is widely regarded as a versatile and remarkable spice. In 2020, India one of the top consumers of chilli—generated over ₹130 billion from its cultivation. Among the 60 insect pests known to affect chilli crops, thrips, especially the invasive species *Thrips parvispinus* (Karny), have emerged as a major threat to Indian agriculture. Initially detected on Carica papaya in 2015 and later on Dahlia rosea Cav., this pest was most recently observed infesting chilli plants in Kerala in 2022. A severe outbreak in 2021 resulted in devastating yield losses ranging from 80% to 100% across southern India. Hence, a rapid roving survey was carried out to assess thrips infestation in chilli crops across farmer's fields throughout Kerala. Thrips specimens were collected from the flowers of infested chilli plants. The predominant species was identified as *T. parvispinus* using the taxonomic key provided by ICAR-NBAIR. Both adult and nymph stages of *T. parvispinus* were found colonizing the underside of leaves and flowers, causing severe curling and crinkling of young leaves at the growing tips. This species exhibits sexual dimorphism, with females having a brown body and males appearing completely yellow. Additionally, other thrips species such as *Scirtothrips dorsalis, Frankliniella schultzei*, Thrips palmi and *Thrips hawaiiensis* were also detected in the flower samples. A field study was carried out to assess the damage caused of *T. parvispinus* infestation on chilli crops. The experiment compared the levels of flower drop, fruit drop, and fruit damage between plots treated with insecticide (three applications of Thiamethoxam 25 WG at 25 g a.i./ha during the 6th , 8th , and 10th weeks after transplanting) and untreated control plots. The findings revealed a marked reduction in damage caused by *T. parvispinus* in the treated plots. Flower drop was lowered by 74.42%, 85.18% and 32.37% at 7, 14 and 21 days after treatment (DAT), respectively. Likewise, fruit drop decreased by 52.98%, 67.21% and 52.23% over the same periods. Fruit damage also showed a significant decline, with reductions of 70.36%, 75.60% and 67.93% at 7, 14 and 21 DAT, respectively. Overall, these findings on bioecology of *T. parvispinus* provide critical insights for the development of integrated pest management approaches for mitigating the threat posed by *T. parvispinus* to chilli and other horticultural crops.

Keywords: Sustainable agriculture, Integrated pest management, Bioecology

RESISTANCE STUDIES IN GREEN GRAM (*Vigna radiata*) PARENTAL LINES AND F1 HYBRIDS AGAINST *Aphis craccivora* KOCH

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ABSTRACT

Green gram (*Vigna radiata*), commonly known as mung bean, is an important legume crop valued for its edible seeds but is highly susceptible to aphid (*Aphis craccivora Koch*) infestation. This polyphagous pest extracts sap from leaves, stems, and pods, thereby reducing photosynthate availability and crop productivity. To address this challenge, six promising green gram genotypes were utilized in a diallel crossing program, resulting in 30 F 1 hybrids that were field-screened for resistance against aphids. Promising hybrids identified from field evaluation were further subjected to laboratory assays to determine the underlying resistance mechanisms. Settling preference studies of *A. craccivora*, involving both free-choice and no-choice tests, revealed reduced aphid settlement on genotype IC-103833 and hybrid P 2 ×P 3 under free-choice conditions, while IC-39272-1 and hybrid P 6 × P 3 exhibited low settling under no-choice conditions. Aphid settling preference showed a significant negative association with trichome density on stems and leaf surfaces (adaxial and abaxial). Furthermore, a negative correlation was observed between aphid settlement and leaf thickness. A similar correlation was also observed with the wax content of leaves and pods. Among the evaluated entries, hybrids P 2 ×P 3 and P 6 × P 3 consistently recorded higher yields with reduced pest incidence, indicating their potential for resistance breeding in green gram.

Keywords: Green gram, Diallel, Hybrid, Resistance, Aphids, Settling preference.

NANOCARRIER-MEDIATED RNAi FOR SUSTAINABLE FRUIT FLIES MANAGEMENT

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ABSTRACT

Fruit flies (*Bactrocera spp. and Ceratitis spp*.) represent one of the most destructive pest groups in fruit crops, leading to heavy yield losses and posing barriers to international trade due to quarantine restrictions. Conventional pesticide-based strategies are increasingly ineffective because of resistance development, environmental hazards, and concerns over chemical residues. RNA interference (RNAi) offers a highly specific and environmentally benign alternative for insect pest management. Nevertheless, practical field deployment faces critical challenges such as dsRNA instability, rapid degradation under environmental conditions, and limited uptake by insect pests. This study focuses on nanocarrier-mediated delivery systems to enhance the stability, bioavailability, and efficiency of dsRNA in targeting essential genes of fruit flies. Biodegradable nanocarriers including chitosan nanoparticles, lipid nanostructures, and layered double hydroxides will be explored for encapsulation and delivery. Evaluation will be carried out in terms of gene silencing efficiency, insect mortality, crop safety, and postharvest residue levels. The integration of RNAi technology with nanodelivery platforms provides a cutting-edge, eco-friendly, and residue-free approach to pest management in fruit crops. This innovation could significantly reduce pesticide reliance and ensure sustainable production systems with enhanced export competitiveness.

Keywords : RNA interference (RNAi); nanocarriers; dsRNA; fruit flies; *Bactrocera dorsalis*; chitosan nanoparticles; gene silencing; sustainable pest management; fruit crops

BIOEFFICACY OF ENTOMOPATHOGENS AGAINST THE SUCKING PESTS OF OKRA

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ABSTRACT

Okra is cultivated in tropical, subtropical and warm temperate regions around the world. The productivity is low due to many factors and one of the most important constraint is the attack of insect pests. Okra is attacked by a number of insect pests results in lower yields. Recently the sucking pests are becoming major pests under changing climatic condition coupled with application of injudicious and spurious pesticides which cause considerable yield loss. The sucking pest complex consisting of aphids (*Aphis gossypii Glover*), leafhopper (*Amrasca biguttula biguttula Ishida*) that caused 17.46 per cent yield loss in okra. Chemical insecticides are sprayed which leads to several problems like toxic residues, elimination of natural enemies, environmental disharmony and development of resistance. Biological control of insect pests using different entomopathogenic microorganisms is gaining importance due to their target specificity, self-perpetuity and obvious safety to the environment. Two field experiments were conducted at the Eastern farm of Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal during rabi and kharif 2023 to evaluate the effectiveness of thiamethoxam 25 WG and a mixture of entomopathogens with (*B. bassiana, M. anisopliae, V. lecanii)* against the sucking pests. Leafhoppers population was low in thiamethoxam 25 WG @ 0.4 g/l (5.93 and 5.79 number/ 3 leaves) with a reduction of (73.85 and 71.23%) followed by *B. bassiana* + *M. anisopliae* + *V. lecanii* @ 15 g/l (6.89 and 6.55 number/ 3 leaves) with a reduction of 69.62 and 67.46 per cent and for the the aphids the overall mean population was low in thiamethoxam 25 WG @ 0.4 g/l (4.74 and 4.70 number/ 3 leaves) with a reduction of (72.37 and 71.54%) followed by *B. bassiana* + *M. anisopliae* + *V. lecanii* @ 15 g/l (5.72 and 5.52 number/ 3 leaves) with a reduction of (66.66 and 67.00%) during both field experiments. The mean population of predatory coccinellids was low in the treatment with thiamethoxam 25WG @ 0.4 g/l (1.33 and 1.18/plant) while a higher population was recorded in the treatments with entomopathogens which ranged from 1.47 to 1.80/plant and 1.45 to 1.76/plant and the mean population of spiders was low in the treatment with thiamethoxam 25WG @ 0.4 g/l (1.52 and 1.58/plant) while a higher population was recorded in the treatments with entomopathogens which ranged from 1.75 to 2.10/plant and 1.81 to 2.08/plant.

Keywords: Entomopathogens, natural enemies, okra, phytotoxicity, sustainability.

HARNESSING NATURE FOR SUNFLOWER SECURITY: ECO-INNOVATIVE IPM APPROACHES AGAINST CAPITULUM BORER (*Helicoverpa armigera*)

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ABSTRACT

Sunflower, a premier oilseed crop, is under persistent threat from the capitulum borer (*Helicoverpa armigera*), which inflicts severe yield losses. Conventional reliance on broad-spectrum insecticides has triggered resistance, pest resurgence, and environmental hazards, necessitating ecologically sound alternatives. To address this challenge, an innovative field study was undertaken during kharif season at Tiruchirappalli, Tamil Nadu, to evaluate Integrated Pest Management (IPM) modules tailored for sunflower. The modules strategically combined eco-friendly options: seed treatment with imidacloprid, foliar application of neem seed kernel extract (NSKE), *Helicoverpa armigera* nucleo polyhedron virus (HaNPV), and reduced-risk insecticides spinosad and emamectin benzoate. Applications were scheduled at critical crop stages to suppress larval infestation effectively. This holistic approach not only minimized capitulum borer incidence but also enhanced ecological balance by reducing dependence on synthetic chemicals. The integration of botanicals, biopesticides and selective molecules represents a nature-aligned innovation that empowers farmers with sustainable and scalable pest management solutions. The findings underscore the potential of eco-innovative IPM frameworks in securing sunflower productivity, safeguarding biodiversity, and moving towards resilient oilseed production. Such strategies exemplify the paradigm shift from pesticide-reliant protection to nature- driven sustainability in Indian agriculture.

Keywords: Sunflower, Helicoverpa armigera, Eco-IPM, Biopesticides, Sustainability

ADJUSTING PLANTING DATES AS AN ECOLOGICAL INNOVATION FOR SUSTAINABLE PEST MANAGEMENT IN RICE

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ABSTRACT

Field experiments were conducted at the Eastern Farm of PAJANCOA & RI, Karaikal, during Rabi and Kharif 2023 to evaluate the effect of varying planting dates on the incidence of key insect pests of rice and the abundance of their associated natural enemies. Three schedules - early, normal, and late planting were compared to assess their role in pest regulation under field conditions. Early planting consistently registered the lowest incidence of stem borer, and leaf folder, indicating that a favorable crop–pest synchrony minimized infestation levels. In contrast, late planting exhibited a pronounced build-up of these pests, leading to greater crop injury and potential yield reduction. Observations on natural enemies revealed that coccinellids and spiders were slightly more abundant in late-planted fields, yet their overall population density remained insufficient to balance pest outbreaks. The study clearly demonstrated that adjusting planting dates, particularly by adopting early planting schedules, can significantly suppress pest populations, reduce crop losses, and contribute to yield stability without additional inputs. This cultural strategy serves as a simple, low-cost, and environmentally sustainable alternative to sole reliance on chemical pesticides. Moreover, it complements integrated pest management (IPM) principles by conserving beneficial organisms, lowering production risks, and enhancing agroecosystem resilience. The findings underscore that fine-tuning planting time represents an important ecological innovation in rice cultivation, offering farmers a practical pathway toward sustainable intensification and reduced ecological footprint in pest management.

Keywords: rice, planting dates, thrips, stem borer, leaf folder, IPM

MICROBIOME-DRIVEN APPROACHES TO ECO-FRIENDLY INSECT PEST MANAGEMENT'

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ABSTRACT

As global agricultural production continues to expand, effective pest management has become essential for maintaining crop health and maximizing yields. Prioritizing food safety and environmental sustainability has increased the need for eco-friendly pest control approaches. Insects naturally harbor diverse microorganisms on their cuticle and within their bodies, which significantly influence their physiology, development, immunity, and behavior. The pest-associated microbiome includes bacteria, fungi, viruses, and protozoa, that can enhance the pest survival, influence the transmission of plant pathogens and provide protection against predators and environmental stresses. Understanding the structure and function of these microbial communities offers a sustainable and novel alternative to chemical pesticides. Strategies such as targeting symbiotic microbes, disrupting microbial-mediated detoxification pathways, or introducing pathogenic microorganisms can reduce pest fitness and population levels. Advances in high-throughput sequencing and metagenomics have enabled detailed characterization of pest microbiomes, revealing microbial taxa that are critical for survival and reproduction. However, variability in microbiome composition across pest populations and environmental conditions poses challenges for consistent application. Though this field of research has both promising opportunities and notable challenges. Advancing this field will deepen our understanding of insect-microbiome dynamics and pave the way for the development of innovative and sustainable strategies for pest management.

Keywords: Insect microbiome, pest management, symbiotic microbes, sustainable agriculture, microbiome-based biocontrol

DIGITAL DECISION SUPPORT TOOLS AND REAL TIME ALERT IN INTEGRATED PEST MANAGEMENT

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ABSTRACT

Digital decision support tools and real-time alert systems are reshaping the way Integrated Pest Management (IPM) is implemented across agricultural and processing environments. By combining data from remote sensors, IoT devices, digital traps, weather models, and pest surveillance networks, these tools enable timely and accurate decision-making. Real-time alerts allow stakeholders to detect pest outbreaks early, apply targeted interventions, and minimize crop losses while reducing reliance on broad-spectrum pesticides. Decision support platforms further enhance IPM by offering risk forecasting, treatment recommendations, and automated reporting based on field-specific conditions. This seminar will explore the role of digital technologies in strengthening early warning systems, optimizing pest control strategies, and supporting sustainable farm and post-harvest practices. It will also highlight practical applications, economic benefits, current challenges, and the future potential of data-driven IPM solutions in promoting precision agriculture and environmental safety.

Keywords: Digital Decision Support, Real-Time Alerts, Integrated Pest Management, IoT and Sensors, Predictive Monitoring, Precision Agriculture

COMPUTER VISION AND DEEP LEARNING FOR PEST COUNTING AND CLASSIFICATION – A REVIEW

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ABSTRACT

Recent advances in computer vision and deep learning have opened new frontiers in pest detection, counting, and taxonomic classification, offering unprecedented precision and scalability in Integrated Pest Management (IPM). Conventional monitoring methods are often to manual, labor-intensive, and prone to observational bias are being rapidly outpaced by automated imaging systems coupled with convolutional neural networks and advanced feature extraction algorithms. These technologies enable high-throughput identification of pest species and life stages from trap images, field surveillance, and storage environments with significantly improved accuracy. Deep learning architectures, such as Faster R-CNN, YOLO, and EfficientNet, facilitate real-time detection and enumeration of pests, even under variable backgrounds, occlusions, and lighting conditions. When integrated with edge devices and cloud-based platforms, these systems provide continuous data streams that support predictive modeling, threshold-based interventions, and population dynamics assessment. This seminar will examine the scientific underpinnings, current applications, validation metrics, and technological constraints of vision-based pest classification. It will also discuss dataset quality, annotation challenges, model transferability across species and regions, and the future trajectory of AI-driven surveillance in agriculture and food safety ecosystems.

Keywords: Computer Vision, Deep Learning, Pest Classification, Automated Counting, Convolutional Neural Networks, Precision IPM

BOTANICAL BULLETS: METHANOL AND PETROLEUM ETHER EXTRACTS OF *Anisomeles malabarica* IN THE BATTLE AGAINST TOBACCO LEAF CATERPILLAR – ECO FRIENDLY PEST MANAGEMENT

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ABSTRACT

The tobacco leaf caterpillar, *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae), is a major polyphagous pest responsible for severe damage in agricultural crops, particularly tobacco, cotton, soybean, and vegetables. Synthetic insecticides, though effective, lead to pesticide resistance, environmental contamination, and non-target effects on beneficial organisms. The present study evaluates the bio-efficacy of methanolic and petroleum ether extracts of *Anisomeles malabarica* Linnaeus (Malabar Catmint), a medicinal and aromatic plant belonging to the family Lamiaceae, against *S. litura.* The study investigated the effects of methanol and petroleum ether extracts of *A. malabarica* leaf on insect development. The methanol extract showed significant effects, with larval mortality ranging from 0-66.67%, pupal malformation from 11.11-55.56%, pupal mortality from 0-55.56%, and adult malformation from 0-22.22%. Specifically, methanol elution 2 recorded the highest larval mortality (66.67%), while elution 3 showed the highest pupal malformation (55.56%). In contrast, the petroleum ether extract did not exhibit any larval mortality or malformation but showed pupal malformation (0-55.56%) and pupal mortality (11.11-55.56%), with adult malformation ranging from 0-33.33%. These findings suggest that both extracts have potential insecticidal properties, with varying effects on different stages of insect development. In addition to assessing mortality and malformation rates, we also measured pupal length and weight to further elucidate the developmental impacts of the extracts. Comprehensive qualitative and quantitative phytochemical analyses were conducted to characterize the bioactive compounds present in the extracts. Notably, methanol elution 2, which exhibited pronounced larvicidal activity and induced significant regurgitation, was subjected to histological examination to investigate the morphological alterations in the larvae. Furthermore, GC- MS analysis was performed on methanol elution 2 to identify the specific compound(s) responsible for the observed larval mortality and regurgitation, thereby providing insight into the underlying mechanisms of action.

Keywords: *Anisomeles malabarica*, Methanol extract, Petroleum ether extract, *Spodoptera litura*

ALKANNIN: A POTENTIAL BIOPESTICIDE FOR SUCKING PESTS

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ABSTRACT

In the aim of producing higher yield of food crops to feed the growing population, there is a shift from natural farming to commercial farming. Problems of pest and diseases are solved using synthetic chemicals, which are non-biodegradable, toxic and leads to biomagnification. Thus, as an alternative to the synthetic pesticides, organic or biopesticide made from secondary metabolites of plants, can be incorporated to achieve sustainability in food supply. The project focuses on the use of Alkannin (a naphthoquinone) present in the roots of *Alkanna tinctoria* (Alkanet) of Boraginaceae family to treat the sucking pests. Alkannin is known for their anti-microbial, anti-viral and pesticidal activity. Alkannin based agro-chemicals are eco-friendly. It was extracted via Soxhlet apparatus with alcohol as solvent. The crude extract was then tested on pests. These compounds are known to produce reactive oxygen radicals, thereby inhibiting mitochondrial respiration. Alkannin can be potentially used as a bio- pesticide, substituting the synthetic chemicals without harming humans and environment.

Key words: Food security, Sustainability, *Alkanna tinctoria*, Sucking pests, Bio-pesticide

BIOEFFICACY OF BOTANICALS AGAINST RUGOSE SPIRALLING WHITEFLY IN GUAVA: AN ECOLOGICAL INNOVATION FOR SUSTAINABLE PEST MANAGEMENT

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ABSTRACT

The rugose spiralling whitefly (RSW), *Aleurodicus rugioperculatus*, has recently emerged as a major invasive pest causing severe damage to guava and other horticultural crops. In order to develop eco- friendly and sustainable strategies for its management, field investigations were conducted on guava variety Arka Rashmi to study the bioefficacy of botanicals, seasonal incidence, and their impact on natural enemies. The biology of RSW revealed extended developmental and reproductive stages that favor its rapid multiplication under field conditions. The management trials demonstrated that among the tested eco-friendly approaches, neem oil exhibited significant adult and nymphal suppression, offering a viable alternative to chemical insecticides. Other botanicals, though less effective, contributed to reducing pest pressure and supported the activity of natural enemies. Population dynamics of RSW indicated seasonal fluctuations closely associated with prevailing weather conditions, with higher incidence observed during specific months. Importantly, plots treated with botanicals harbored greater numbers of predatory spiders and coccinellids, highlighting their compatibility with natural enemy conservation. In contrast, chemical treatments resulted in marked reduction of beneficial arthropods, underlining the ecological advantage of botanicals in integrated pest management. The findings emphasize that integrating botanicals such as neem oil within pest management frameworks not only suppresses pest populations effectively but also sustains ecological balance through natural enemy preservation. This study underscores the role of botanicals as ecological innovations for sustainable pest management in guava cultivation, reducing reliance on synthetic insecticides and promoting environmentally resilient cropping systems.

Keywords: Rugose spiralling whitefly, guava, botanicals, neem oil, natural enemies, sustainable pest management

ECO-FRIENDLY INTEGRATED PEST MANAGEMENT OF *Noorda moringae* AND *Noorda blitealis* IN MORINGA (*Moringa oleifera* LAM.)

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ABSTRACT

Moringa (*Moringa oleifera Lam.)* is a multipurpose crop widely cultivated in tropical regions, but its productivity is severely constrained by the budworm *(Noorda moringae Tams*) and the leaf-eating caterpillar (*Noorda blitealis Walker).* The present study aimed to evaluate the efficacy of biorationals and chemical insecticides against these pests and to develop an eco-friendly Integrated Pest Management (IPM) module. Field trials conducted at Puliampatti, Tiruppur district revealed that among biorationals, Azadirachtin 300 PPM was most effective against *N. moringae*, reducing bud infestation by 53.84% over the control, followed by Bacillus thuringiensis (49.50%). Among insecticides, Chlorantraniliprole 18.5 SC recorded the highest reduction (75.38%), followed by Emamectin benzoate 5 SG (70.18%), and Spinosad 45 SC (64.92%). Against *N. blitealis, Azadirachtin* 300 PPM again showed maximum efficacy (58.32%), followed by neem oil (55.75%) and B. thuringiensis (50.72%). Spinosad 45 SC was the most effective insecticide (84.69%), with Chlorantraniliprole 18.5 SC (82.43%) and Indoxacarb 15.8 EC (77.12%) also performing well. Based on the results, an IPM module was developed integrating soil raking, light traps, Azadirachtin 300 PPM, and need-based applications of Spinosad 45 SC and Chlorantraniliprole 18.5 SC. This strategy significantly outperformed farmers' practice, recording the lowest budworm infestation (15.52%) and leaf caterpillar load (4.25 larvae/branch). It also resulted in the maximum pod yield (9674 kg/ha) with a higher benefit-cost ratio (1:2.88), compared to 8021 kg/ha (1:2.27) under farmers' practice. The study underscores that integrating biorationals with reduced-risk, green-labelled insecticides provides a sustainable and economically viable approach to manage N. moringae and *N. blitealis* in moringa ecosystems.

Keywords: *Moringa oleifera*, *Noorda moringae*, *Noorda blitealis*, Integrated Pest Management (IPM), Biorationals

IPM AND THE FUTURE OF FOOD PRESERVATION: A SUSTAINABLE APPROACH

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ABSTRACT

Integrated Pest Management (IPM) represents a paradigm shift in agricultural sustainability, offering a holistic framework that minimizes pest-related losses while safeguarding environmental and human health. As global food systems grapple with post-harvest deterioration and mounting pressure to reduce chemical residues, IPM emerges as a pivotal strategy in enhancing the shelf life of food commodities. This abstract explores the synergistic relationship between IPM practices, including biological control, cultural interventions and judicious pesticide use and the preservation of food quality during storage and transit. By mitigating pest infestations at critical control points, IPM not only curtails spoilage but also maintains the nutritional integrity, aesthetic appeal, and marketability of produce. The integration of IPM into post-harvest protocols contributes to reduced reliance on synthetic preservatives, aligning with consumer demand for safer, residue-free food. Furthermore, IPM supports compliance with international export standards, thereby expanding market access for agricultural products. This paper underscores the role of IPM in shaping resilient food supply chains and calls for interdisciplinary collaboration to refine pest management strategies that extend shelf life without compromising ecological balance. Through case studies and emerging innovations, it advocates for IPM as a cornerstone of sustainable food preservation in the 21st century.

Keywords: Integrated Pest Management, shelf life, nutritional integrity, ecological balance and food preservation

NEXT-GEN IPM IN POST-HARVEST MANAGEMENT: BRIDGING SCIENCE AND TRADE

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ABSTRACT

The post-harvest phase of agricultural production is increasingly vulnerable to pest infestations, which compromise food safety, reduce marketable yields, and hinder export potential. Integrated Pest Management (IPM), traditionally applied during crop cultivation, is now being reimagined for post- harvest systems to address these challenges with precision and sustainability. This abstract explores next-generation IPM strategies that integrate scientific innovation, regulatory compliance, and market intelligence to safeguard stored commodities and enhance global trade readiness. The emerging technologies, such as sensor-based pest detection, controlled atmosphere storage, and biopesticide applications, offer targeted, residue-free solutions that align with international phytosanitary standards. These interventions not only reduce reliance on chemical fumigants but also support traceability, certification and consumer trust. Commodity-specific IPM protocols, developed through interdisciplinary research, are enabling producers to meet the stringent quality benchmarks of high- value export markets. The paper further examines institutional frameworks, capacity-building models, and public-private partnerships that facilitate the adoption of IPM in post-harvest contexts. Emphasis is placed on harmonizing scientific rigour with trade facilitation, ensuring that pest management practices contribute to both ecological sustainability and economic competitiveness. By bridging science and trade, next-gen IPM transforms post-harvest management into a strategic lever for agricultural advancement, food security, and global market integration.

Keywords: Integrated Pest Management, sensor-based pest detection, controlled atmosphere storage, biopesticide application and food security

BACTERIAL ENDOPHYTES AS BIOCONTROL AGENTS: A SUSTAINABLE APPROACH TO INSECT PEST MANAGEMENT

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ABSTRACT

Bacterial endophytes are microscopic prokaryotic organisms that maintain a symbiotic association with their host plants, contributing to growth promotion and defense against insect pests and pathogens. Extensive research has identified beneficial strains of bacterial endophytes capable of suppressing plant diseases and enhancing plant development through mechanisms such as induced systemic resistance (ISR). ISR is activated by bioactive compounds produced when a plant interacts with an endophyte, later resulting in systemic acquired resistance (SAR) upon insect or pathogen infestation. Notable examples include *Bacillus amyloliquefaciens*, producing lipopeptides to induce plant resistance against pests like the fall army worm, and Enterobacter cloacae, which acts as a biocontrol agent against rice pests through protein production. Transgenic endophytic bacteria, such as *Clavibacter xyli* subsp. cynodontis carrying the cry1A gene, exhibit insecticidal activity against lepidopteran pests. Studies on cabbage and related crops have shown that isolates of *Enterobacter cloacae, Alcaligenes piechaudii*, and *Kluyvera ascorbata* can effectively manage diamondback moth populations. These findings highlight the potential of bacterial endophytes as sustainable biocontrol agents in modern agriculture.

Keywords: bacterial endophytes, insect pest management, biocontrol, induced systemic resistance, *Bacillus amyloliquefaciens*, Enterobacter cloacae, *Clavibacter xyli*, sustainable agriculture

HARNESSING NATURE: ECOLOGICAL INNOVATIONS FOR SUSTAINABLE PEST MANAGEMENT

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ABSTRACT

A revolutionary move away from chemical-focused, short-term pest management techniques targeted towards integrated, sustainable methods based on ecological principles is represented by ecological innovations in pest management. With little consideration given to their interactions and compatibility, traditional pest control techniques frequently rely on single technologies, such as pesticides or biocontrol agents, with little chance of long-term success. A comprehensive grasp of agroecosystem dynamics, including local population biology and multitrophic interactions, is necessary for a truly effective pest management system, according to recent research. A key framework for reducing environmental impact and improving crop resilience is Integrated Pest Management (IPM), that combines targeted pesticide applications, biological control, genetic strategies, and cultural practices. Microbial biopesticides, enhanced delivery methods, and landscape-level interventions are examples of recent developments in integrated pest management. In addition, the Sterile Insect Technique (SIT) is an eco-friendly method that controls pest populations by releasing sterilized males, reducing reproduction and pest outbreaks while supporting sustainable, chemical-free pest management.

Keywords: Ecological pest management, Integrated Pest Management (IPM), Sustainable agriculture, biological control, Agroecosystem dynamics, Sterile Insect Technique (SIT).

RNAi-MEDIATED GENE SILENCING IN BPH – A REVIEW

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ABSTRACT

Brown Planthopper (*Nilaparvata lugens*) remains a critical pest in Asian countries, causing severe damage to crops, reducing overall production. With the available integrated pest management strategies and increasing resistance of BPH towards the method of control, it is crucial to include new technologies in controlling these pests. Recent studies show the role of the tramtrack(ttk) gene in male reproductive development and spermatogenesis of BPH. The research demonstrates that RNAi-mediated knockdown of ttk impairs male gonad development, reduces sperm count and motility, and drastically decreases fertility, indicating ttk as an effective molecular target for pest control. This work exemplifies the potential of RNAi as a species-specific, environmentally friendly approach aligned with integrated pest management (IPM) goals. This type of research paves the way for sustainable, precise, and reduced-chemical pest control in modern agriculture, contributing to improved crop protection and food security.

Keywords: Brown planthopper, RNAi, gene silencing, tramtrack (ttk), fertility.

COLD PLASMA TREATMENT FOR STORAGE PEST MANAGEMENT

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ABSTRACT

Insect pests in stored commodities cause major postharvest losses, posing risks to global food security. While chemical fumigants are traditionally used, their effectiveness is increasingly limited by resistance, toxic residues, environmental concerns, and health hazards. Cold plasma (CP), a non-thermal and eco-friendly technology, has emerged as a potential alternative, offering insecticidal, antimicrobial, and seed-preserving benefits. This review highlights CP's working principles, modes of action, practical uses, and limitations in storage pest management, emphasizing its promise as a sustainable replacement for chemical fumigants.

Key words: Storage pest, cold plasma treatment, seed storage

Introduction

Stored-product pests contribute to substantial losses, estimated at 10–30% of global grain stocks(Srivastava and Subramanian, 2016). Prominent species include Sitophilus oryzae (rice weevil),*Tribolium castaneum* (red flour beetle), and *Callosobruchus chinensis*(pulse beetle). Their activity reduces grain weight and yield, degrades nutritional quality, and lowers seed viability. Infestations also encourage fungal growth and mycotoxin production,compounding food safety risks (Eigenbrode et al., 2018).To date, multiple studies have investigated alternative methods to the use of chemical pesticides. These include natural plant-derived components (Deb et al., 2020; Singh and Kaur, 2018) entomopathogenic bacteria and nematodes (Ramos-Rodríguez et al., 2006;Malaikozhundan and Vinodhini, 2018; de Bortoli and Jurat-Fuentes, 2019) insect growth regulators (Wijayaratne et al., 2018) physical control methods, such as heat, cold, and modified atmosphere technology [Navarro, 2012; Fields and White, 2002; Agrafioti, 2019]ozone (Hardin et al., 2010) ionizing radiation (Hallman, 2013) and combined treatment approaches (Kostyukovsky et al.,2016). Traditional fumigants, such as methyl bromide and phosphine, are effective but face challenges like resistance, occupational hazards, and regulatory restrictions (Silva et al., 2019). These limitations create a need for innovative, non-chemical, and environmentally sustainable pest management solutions. Cold plasma has emerged as a promising approach due to its broad-spectrum activity and minimal effect on grain quality Fundamentals of Cold Plasma Technology Cold plasma is a partially ionized gas generated at or near room temperature using electrical discharges, including dielectric barrier discharge (DBD), plasma jets, and corona discharges (Bourke et al., 2018). It produces reactive oxygen and nitrogen species (ROS,RNS), free radicals, electrons, ions, and UV radiation. Unlike high-temperature plasmas, CP can safely treat heat-sensitive materials such as grains, seeds, and other stored foods. Its reactive species interact with insect exoskeletons, microbial cells, and seed surfaces, offering insecticidal, antifungal, and quality-preserving effects (Misra et al., 2019).

Mechanisms of Cold Plasma in Pest Control

- CP exerts pest control through multiple mechanisms:
- Cuticle damage: ROS and charged particles disrupt the insect cuticle and spiracles,hindering respiration (Laroussi and Leipold, 2004).
- Oxidative stress: Overproduction of ROS/RNS damages lipids, proteins, and DNA, leading to cellular dysfunction.
- Enzyme disruption: Antioxidant enzymes, including SOD, catalase, and GST, are impaired reducing insect resilience (Ziuzina et al., 2021).
- Reproductive inhibition: Plasma treatment decreases egg viability and larval growth, limiting population expansion (Pathan et al., 2021).
- Microbial suppression: Fungi and bacteria associated with pests are inactivated, indirectly reducing infestation levels.
- This multimodal approach contrasts with conventional insecticides, which usually target specific physiological pathways. (Ziuzina et al. (2021)

Applications in Stored Grain Protection

Cold plasma has been shown effective against key storage pests:

- Pulse beetle *(C. chinensis*): Plasma exposure lowers adult survival and reduces egg hatchability (Pathan et al., 2021).
- Rice weevil (*S. oryzae*): CP treatment decreases survival, reproduction, and larval development (Mohammadi et al., 2015).
- Red flour beetle (*T. castaneum*): Larvae and pupae are highly susceptible to plasma exposure (Abd El-Aziz et al., 2014).

Additional benefits include:

- Seed quality enhancement: Improved germination, vigor, and water uptake.

- Fungal and mycotoxin control: Inactivation of Aspergillus and Fusarium reduces aflatoxin and ochratoxin contamination (Khamsen et al., 2016).

- Preservation of nutritional and sensory properties: Appropriate plasma doses maintain grain quality.
- Integration potential: CP can be combined with hermetic storage, modified atmospheres, or biological control agents. Advantages and Limitations

Advantages:

- Chemical-free and environmentally sustainable.
- Broad-spectrum efficacy against insects, fungi, and microbes.
- Enhances seed germination and storage quality.
- Considered a "green technology" suitable for integrated pest management.

Limitations:

- Limited penetration in bulk grains; surface treatment is most effective.
- High initial cost and energy requirements.
- Standardized operational protocols are lacking.
- Regulatory approval for food applications remains limited.

Future Prospects

Wider adoption of CP requires:

- Development of scalable plasma devices for silos and warehouses.
  Optimizing plasma flow for uniform insecticidal coverage.
- Energy-efficient systems, including solar or hybrid plasma units.
- Interdisciplinary collaboration among entomologists, food scientists, and plasma engineers. Establishment of regulatory standards for safe food applications.

Conclusion

Cold plasma is a promising, eco-friendly alternative for storage pest management. Its multifunctional effects-pest suppression, fungal/mycotoxin control, and seed-quality enhancement-make it a viable substitute for chemical fumigants. Though challenges remain in scaling, cost, and regulation, ongoing technological advancements may position CP as a mainstream component of integrated pest management, promoting sustainable storage and global food security.

A REVIEW OF SOOTY MOLD ON MANGO (*Mangifera indica* L.): ETIOLOGY, IMPACT, AND INTEGRATED MANAGEMENT

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ABSTRACT

Sooty mould disrupts mango output worldwide, especially in humid areas with many honeydew producing insects. Recent research on mango orchard sooty mould etiology, impact, and integrated management is summarised in this review. Sap sucking insects like mango hoppers *(Amritodus atkinsoni*),mealybugs (*Drosicha mangiferae*), and scales cause the problem. The sugary honeydew secreted by these pests feeds epiphytic fungal species as *Meliola mangiferae, Capnodium mangiferae*, and *Aspergillus spp*.The primary impact of sooty mold is indirect. The dense, black fungal mat on leaves and twigs blocks sunlight, reducing photosynthetic capacity and gas exchange. Even though the fruit pulp represents unaffected, the sooty coating decreases aesthetic appeal, market value, and export potential. Rainfall and insect pest population density significantly influence infestation severity. Insect infestations are best managed by targeting the root cause, not just the fungi. Reviewing control strategies:

Chemical Control: Application of systemic insecticides to control sap sucking pests.

Organic/Natural Control: Neem oil and insecticidal soaps destroy pests and remove mold. A spray of water and mild detergent can treat small infections.

Mechanical Removal: Physical removal of the sooty mold using a boiled starch solution, which dries and flakes off with the fungal growth.

Post-Harvest Treatments: Techniques like dipping fruits in specialized washes to remove blemishes and restore market quality.

Cultural Practices: Regular pruning increases airflow and sunlight,reducing mold formation.

Most sustainable and successful technique to reduce sooty mould ecological and economic impact on mango production is an integrated biological,cultural, and targeted chemical IPM strategy.

Keywords: Mango, sooty mold, *Meliola mangiferae*, honeydew, sucking pest, integrated pest management (IPM), photosynthesis, fruit quality.

SOCIOECONOMIC DETERMINANTS AND BEHAVIORAL DRIVERS OF DIGITAL IPM ADOPTION TOOLS AMONG FARMING COMMUNITIES

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ABSTRACT

The study examined the socioeconomic determinants and behavioral drivers influencing the adoption of digital Integrated Pest Management (IPM) tools among farmers in Chengalpattu district, using data from 120 respondents collected through interview schedules and focus group discussions. Descriptive statistics, correlation analysis, and logistic regression were employed to analyze awareness, usage, and adoption behavior. Results revealed that while 66.6% of farmers were aware of digital IPM tools, only 36.7% used them either regularly or occasionally. Key socioeconomic factors—education, digital literacy, farm size, and extension contact—showed strong positive correlations with adoption, while age was negatively associated. Behavioral factors such as perceived usefulness, trust in digital advisories, ease of use, and peer influence significantly shaped adoption decisions, with perceived usefulness having the highest predictive influence in the logistic regression model.The findings highlighte that digital IPM adoption is driven by a combination of technological perception and social-economic readiness. Strengthening digital literacy, enhancing trust through locally relevant advisories, and integrating user-friendly, multilingual platforms were the essential suggested policy measures to bridge the gap between awareness and effective utilization of digital IPM tools in rural farming systems.

Keywords: Digital Integrated Pest Management (IPM), Technology Adoption, Socioeconomic Determinants, Behavioral Drivers

HOST PLANT SUSCEPTIBILITY INDEX OF OKRA GENOTYPES AGAINST LEAFHOPPER AND ITS ASSOCIATION WITH NUTRIENT CONTENT

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ABSTRACT

Two field studies were conducted at the Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore, to assess the host plant susceptibility index of selected okra genotypes against the leafhopper, *Amrasca biguttula biguttula* Ishida, and to establish the relationship between leaf nutrient composition and pest incidence. Significant variation in leafhopper incidence was observed among the tested okra genotypes. The mean population of leafhopper was consistently higher inhighly susceptible genotypes AE 26 and AE 15, followed by Pusa Sawani and AE 64, while the lowest infestation was recorded in AE 65 (moderately resistant) and Arka Anamika. Based on the pooled data of two field trials, the host plant susceptibility index (HPSI) indicated AE 26 as highly susceptible,AE 15 and Pusa Sawani as susceptible, AE 64 as moderately susceptible, while AE 65 and Arka Anamika were categorized as moderately resistant genotypes. Nutrient composition analysis revealed distinct differences among the genotypes. Nitrogen content was maximum in AE 26 (3.66%), followed by Pusa Sawani (3.48%) and AE 15 (3.32%). Phosphorus content was higher in AE 15 (0.18%) and AE 26 (0.16%), whereas potassium content was maximum in AE 65 (1.43%) and Arka Anamika (1.36%). Correlation studies showed that nitrogen ($r = 0.872$) and phosphorus ($r = 0.737$) were positively correlated with leafhopper population, while potassium ($r = -0.971$) exhibited a strong negative correlation. The results suggest that higher nitrogen and phosphorus levels in okra foliage may enhance the susceptibility to leafhopper attack, whereas increased potassium concentration contributes to tolerance or resistance. These findings emphasize the potential role of nutrient management and host plant resistance in integrated pest management strategies.

Key words: Okra, leaf hopper, HPSI, nutrient content, resistance

NATURE'S SHIELD FOR ECO-FRIENDLY SEED STORAGE PEST CONTROL

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ABSTRACT

Sustainable pest management in seed storage systems is increasingly vital as the overuse of synthetic fumigants and insecticides poses serious risks to human health, seed viability, and ecological balance. This study focuses on Nature's Shield, an integrated framework employing eco-friendly and technologically advanced strategies for controlling storage pests while maintaining seed quality. Recent innovations such as nanotechnology-based biopesticides,biopolymer coatings infused with essential oils, and microbial antagonists like Bacillus subtilis and Beauveria bassiana demonstrate high efficacy in suppressing pest populations through biological and physical mechanisms. In parallel, smart sensor networks and IoT-based monitoring systems are transforming storage environments by enabling real-time tracking of temperature, humidity, and pest movement. Furthermore, the application of machine learning algorithms enhances predictive modeling for early pest detection, allowing for timely and precise interventions. Controlled atmosphere storage (CAS) and modified humidity management systems further contribute to the suppression of pest development while reducing chemical dependency. Collectively, these technologies form a synergistic, sustainable approach to seed preservation, promoting long-term storage stability and biosecurity. The integration of ecological principles with digital innovations presents a viable pathway toward minimizing post-harvest losses, enhancing seed longevity, and ensuring food system resilience. The findings emphasize that eco-technological convergence can provide scalable, non-toxic, and environmentally compatible alternatives to traditional pest management practices.

Keywords: Eco-friendly Pest Management; Seed Storage Protection; Nanobiotechnology; Smart Monitoring Systems; Biological Control

INFLUENCE OF WEATHER PARAMETERS ON NATURAL PARASITIZATION OF *Helicoverpa armigera* BY *Campoletis chloridaeae* UCHIDA IN CHICKPEA ECOSYSTEM OF THE NEW ALLUVIAL ZONE OF WEST BENGAL

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ABSTRACT

The gram pod borer (Helicoverpa armigera Hübner) is a major pest of chickpea *(Cicer arietinum L.*), naturally regulated by the endo-larval parasitoid *Campoletis chloridaeae* Uchida. This study examined the influence of weather parameters on the parasitization rate of *C. chloridaeae* in chickpea ecosystems of the new alluvial zone of West Bengal. Field experiments conducted for three consecutive Rabi seasons (2017–18 to 2019–20) at Mondouri Farm, BCKV, followed a randomized complete block design. Second-instar larvae of H. armigera were reared until cocoon formation, and parasitization percentage was related to weather variables using correlation and stepwise regression analyses. The parasitoid appeared during the third standard meteorological week with a peak parasitization of 68– 72% at flowering to pod initiation stages. Maximum and minimum temperatures showed significant negative correlations with parasitization, explaining about 50% of its variation. Rising temperatures may reduce *C.chloridaeae* efficiency, necessitating climate-resilient IPM strategies in chickpea.

Keywords: *Helicoverpa armigera*, *Campoletis chloridaeae*, Parasitization rate, Weather parameters, Integrated pest management.

BACTERIOPHAGES – A NOVEL BIOPRESERVATIVE FOR VEGETABLES

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ABSTRACT

Survey was conducted on farmer's field for examination of soft rot incidence in vegetable growing regions of Tamil Nadu. Rotten potatoes and tomatoes with soft rot symptom were collected from farmer field and market. Screening of the isolates was performed based on rot zone, rot weight, rot severity and polygalacturonase activity.Based on the screening, isolate PP 4, PP 1, PP 3, PE 1, PE 6, PE 11, PE 19, TE 8, TE 1,TE 3, TE 9, TE 12, TE 13, TE 18 and TE 21 were selected as virulent pathogens by comparison with the standard culture Pectobacterium carotovorum subsp. *Carotovorum* ATCC 39048. Isolates that were considered to be soft rot causing species were characterized and identified on the basis of conventional phenotypic and biochemical characteristics. Screened isolates were identified using molecular characterization as PP 1 (*Cellulomicrobium funkei*), PP 2 (Enterobacter asburiae), PP 3 (*kocuria palustris*),PP 4 (*Pectobacterium carotovorum* subsp.*carotovorum*), PE 6 (*Bacillus subtilis*), PE 11 *(Bacillus aryabhattai*), PE 1 (*Arthrobacter nicotianae*) and PE 19 (*Klebsiella oxytoca*) from rotten potato and TE 1 (*Lactobacillus pentosus*), TE 8 (*Citrobacter freundii*), TE 12 (*Enterobacter hormaechei*), TE 13 (*Klebsiella variicola*), TE 18(Enterobacter cloacae subsp. cloacae), TE 21 (*Klebsiella pneumonia*), Lactobacillus from tomato.Isolates were tested for its various host range and found to have wide host range on Tomato, Onion, Okra, Carrot, Cabbage, Radish, Broccoli, Radish, Cauliflower, Ivy gourd, Capsicum, Brinjal, Potato, Tomato and Lettuce. In the host range infectivity analysis, brown discoloration and decaying symptoms identical to soft rot symptom were observed up to a week after inoculation, whereas negative control treatments remain symptomless in all vegetables tested. TE 8 (*Citrobacter freundii*) had a broad host range infecting all families of vegetables except Onion,Broccoli, Radish, Ivygourd, Capsicum, Potato and Lettuce in secondary screening. TE 12 (*Enterobacter hormaechei*) and TE 21 (*Klebsiella pneumonia*) had a host range on onion. PP 4(Pectobacterium carotovorum subsp. carotovorum) had a broad host range infecting all families of vegetables except Brinjal in secondary screening. PP-1 (*Cellulosimicrobium funkei*) had a host range on Capsicum, Potato and Lettuce. PP 2 (*Enterobacter asburiae*) and PP-3 (*Kocuria palustris*) were virulent on Capscicum and potato. PE 1 (*Bacillus subtilis subsp. inaquosorum*), PE-6 (*Bacillus aryabhattai)* and PE 11*(Arthrobacter nicotianae*) infects onion and potato. PE 19 (*Klebsiella*

oxytoca) could spoil onion, potato and as well as tomato.Cellulase and pectinase enzyme activity was determined for the screened isolate using agar cup assay. The performance of standard culture *Pectobacterium carotovorum* subsp. carotovorum ATCC 39048 was compared for screening virulent isolates like PP 1, PP 2, PP 3, PP 4, PE 6, PE 11, PE 1, PE 19, TE 1, TE 3, TE 8, TE 9,TE 12 and TE 13. PP 4 (*Pectobacterium carotovorum subsp. carotovorum*) from potato and TE-8 *(Citrobacter freundii*) from tomato has higher pectinolytic activity and celluloytic activity among those virulent isolates in secondary screening. Healthy,naturally infected and artificially screened pathogens inoculated potato and tomato on third day were evaluated for differential polyphenoloxidase activity, total phenolic compound, titratable acidity, pH, soluble solids content, reducing sugars, colour and firmness. Increase in reducing sugars, total soluble solids, polyphenoloxidase activity,total phenolic compound and decrease in firmness and colour in infected potato than the healthy exactly indicates the quality changes of potato by spoilage pathogens. Pathogenesis related proteins were up regulated and disease resistant inhibitor proteins were down regulated indicating respectively in both naturally infected and *P.carotovorum subsp. carotovorum* (PP 4) inoculated when compared with the healthy tissue.Totally four phages were isolated from rhizosphere soil from Coimbatore,Dindigul and Niligris against spoilage bacteria (PP-4) *Pectobacterium carotovorum* subsp. *carotovorum* and six phages for (TE 8) Citrobacter freundii. Phages were purified by streak method of purification with slight modification. Host ranges of phages were determined for its lytic activity. VegsavPhage 7 had a wide host range infecting major spoilage bacteria TE 1 of Enerobacterioceae family (*Lactobacillus pentosus*), TE 8 (*Citrobacter freundii*), TE 12 (*Enterobacter hormaechei)*, TE 13(*Klebsiella variicola*), TE 18 (*Enterobacter cloacae subsp. cloacae*), TE 21 (*Klebsiella pneumonia*), PP 2 (*Enterobacter asburiae*) PP 3 *(Kocuria palustris*), PP 4(*Pectobacterium carotovorum* subsp. *carotovorum*), PE 1 (*Bacillus subtilis subsp.inaquosorum*), PE 11 (*Arthrobacter nicotianae)* and PE-19 (*Klebsiella oxytoca*)followed by phage 5 having host range for TE 1 *(Lactobacillus pentosus*), TE 8(*Citrobacter freundii*), TE 12 *(Enterobacter hormaechei*), TE 13 (Klebsiella variicola),TE 18 (Enterobacter cloacae subsp. cloacae), TE 21 (Klebsiella pneumonia), PP 2(*Enterobacter asburiae*) PP 3 (*Kocuria palustris*), PP 4 *(Pectobacterium carotovorum* subsp. *carotovorum)*, PE 1 (*Bacillus subtilis subsp. inaquosorum*) and PE 19(*Klebsiella oxytoca*).Titer values of phage stocks in SM buffer were examined. Phage titre was around 15 x 10 13 pfu/ ml. PP 4 and TE 8 become resistant to all the phages at 48 hrs. 24 hrs was optimum for harvest of phages. Spoilage of potato and tomato was controlled by phage and had better biopreservative efficiency. Rot weight, rot severity, rot zone and population were reduced compared with

inoculated control. VegsavPhage 7 has broad host range, lesser resistant to Pectobacterium and exhibited better biopreservative efficiency whilst screening. Hence, growth cycle of Phage 7 was estimated up to one hour. Latent period was up to 30 minutes. Rise period was around 15 min. Burst size was 8 x 10 6 pfu/ml. Vegsavphage 7 was multiplied in one litre flask and they were filtered and stored. AFM has revealed the morphology of bacteriophage named vegsavphage 7, belongs to Myoviridae family (T 4). Repeated oral toxicological study was conducted on wister rats for bacteriophages (T 4). The results were much fruitful because they were safe to humans because no toxicity in rats. It could be better exploited as a biopreservative for vegetables by entrapping them in the microspheres of protein film coated over the vegetables. Coated films over vegetables are water soluble and could be washed before cooking. It prevents the spoilage due to pathogens and enhances the shelf life of vegetables up to 50 days. The study presented here has established the proof of concept, Bacteriophages - A novel biopreservative for vegetables against spoilage/opportunistic pathogens.

Keywords: Bacteria, Phages, Vegetables, Pathogens

BIOACOUSTIC SURVEILLANCE SYSTEMS FOR DETECTING INSECT FOR SUSTAINABLE AGRICULTURE

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ABSTRACT

Effective management of agricultural insects depends on the timely and accurate detection of pest populations to minimize crop damage and enhance control efficiency. Conventional monitoring techniques, including visual scouting and pheromone trapping, are often limited in sensitivity, particularly for cryptic or endophytic species such as stem borers (*Chilo partellus*), wood-boring beetles, termites, and subterranean root feeders that remain concealed within plant tissues or soil environments. Bioacoustic surveillance has emerged as an innovative, non-invasive approach that capitalizes on the distinct vibrational and airborne acoustic signals generated by pest activities such as feeding, locomotion, and stridulation. Highly sensitive transducers, including piezoelectric contact microphones and accelerometers, are deployed on plants, tree trunks, or within the soil to detect these pest-generated vibrations. Advanced signal processing and machine learning algorithms facilitate the discrimination of pest-specific acoustic patterns from ambient environmental noise caused by wind, rain, or non-target organisms. Integration of bioacoustic data with agronomic parameters such as crop phenology, soil moisture, and microclimatic variables enables spatially and temporally resolved assessments of pest populations. This supports precision intervention strategies within integrated pest management (IPM) frameworks, reducing unnecessary pesticide use and improving sustainability. Although challenges remain regarding sensor placement optimization, background noise management, and the establishment of comprehensive acoustic reference libraries, recent advancements in wireless sensor networks, edge computing, and artificial intelligence have substantially enhanced detection accuracy, real-time responsiveness, and system scalability.Consequently,bioacoustic surveillance represents a transformative technology for sustainable, data-driven pest management in modern agriculture.

Key words- Bioacoustic, Sensor, Surveillance, Vibration, Signal

THE MICROBIAL SHIELD: HARNESSING PLANT-MICROBIOME INTERACTIONS FOR PEST RESILIENCE

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ABSTRACT

The escalating demand for sustainable agriculture has intensified research into plant-microbiome interactions as an innovative alternative to conventional pest control methods. Plants coexist with complex and dynamic microbial communities collectively termed the plant microbiome that colonize the rhizosphere, phyllo sphere, and endosphere. These microbial assemblages are increasingly recognized as critical allies in enhancing plant health,particularly in bolstering resilience against pests. This concept of a microbial shield emphasizes the natural capacity of beneficial microbes to prime plant defences, compete with or antagonize pathogens and herbivorous insects, and modulate host signalling pathways involved in stress responses. This review explores the multifaceted mechanisms through which the plant microbiome contributes to pest resistance, including the induction of systemic resistance (ISR), production of volatile organic compounds (VOCs), and manipulation of insect behaviour via microbial metabolites. We examine recent advances in metagenomics, transcriptomics, and synthetic biology that enable deeper understanding and targeted manipulation of these interactions. Case studies from agricultural systems demonstrate how specific microbial taxa such as Pseudomonas, Bacillus, and mycorrhizal fungi can be harnessed as biocontrol agents to suppress pest populations, reduce reliance on chemical pesticides, and promote crop productivity. Furthermore, we discuss the challenges in translating laboratory findings into field applications, including microbiome stability, environmental variability, and host-specific responses. The integration of microbiome-based strategies into pest management frameworks represents a paradigm shift towards ecological intensification, where biological diversity is leveraged to enhance crop resilience. By decoding and engineering the plant microbiome, agriculture stands at the frontier of developing a sustainable microbial shield against pest pressures in the face of climate change and growing global food

demands.

Key words- Sustainable, Microbiome, Pest population, Resilience, Biocontrol agents.

IMPACT OF SPIDES ON SLAUGHTER CHARACTERISTICS OF BROILER CHICKENS FROM LONG-TERM STORED EGGS

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ABSTRACT

This experiment assessed the effects of Short Periods of Incubation During Egg Storage (SPIDES), applied with or without egg turning, on the slaughter traits of broilers hatched from eggs stored for an extended period. A total of 750 hatching eggs obtained from 33.5-week-old breeder hens were randomly distributed into five treatment groups: T1 (control, no SPIDES), T2 (three SPIDES without turning), T3 (three SPIDES with turning), T4 (four SPIDES without turning), and T5 (four SPIDES with turning). Eggs were maintained at a temperature of 17 °C and 75% relative humidity, while those subjected to SPIDES were periodically heated to 37.7 °C for three hours at five-day intervals. All eggs were stored for 21 days and transferred for incubation on the 22nd day. Among the treatments, T5 exhibited the highest New York dressing yield (90.45%), dressed weight percentage (74.19%), ready to-cook weight (79.78%) and liver weight percentage (2.91%). No significant differences were observed in the small intestine, gizzard, heart, breast, neck, ribs and back, thigh and drumstick weight percentage among the groups. However, T2 (3 SPIDES without turning) had the highest wing weight percentage (12%).These findings suggest that SPIDES, particularly with turning, enhances carcass yield parameters in broilers.

***Keywords*:** SPIDES, hatching eggs, broiler slaughter traits, carcass yield

INFLUENCE OF DIETARY AZOLLA ON GROWTH AND PERFORMANCE PARAMETERS IN COMMERCIAL BROILERS CHICKEN

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ABSTRACT

This study investigated the effect of dietary supplementation of dried Azolla at different inclusion levels on production performance parameters of commercial broiler chickens. A total of 250-day-old broiler chicks were randomly divided into five treatment groups: T1 (Control: 100% commercial feed), T2 (1% Azolla + 99% commercial feed), T3 (3% Azolla + 97% commercial feed), T4 (5% Azolla + 95% commercial feed), and T5 (7% Azolla + 93% commercial feed). All birds were reared under standard management practices for the duration of the experiment. Significant differences were observed among the treatment groups for body weight, feed consumption, feed conversion ratio, and livability. Among all treatments, broilers fed 5% Azolla with commercial feed (T4) demonstrated the best overall production performance. In conclusion, dietary inclusion of dried Azolla, particularly at 5%, can effectively enhance growth and production parameters in commercial broiler chickens.

Keywords: Azolla, body weight, feed consumption, feed conversion ratio, livability, broiler

DIGITAL TRANSFORMATION IN THE PEST MANAGEMENT OF FRUIT CROPS

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ABSTRACT

The rapid evolution of digital technologies has revolutionized the terrain of Integrated Pest Management (IPM) in fruit crops. Traditional pest management approaches, often reliant on chemical control, faces many challenges due to pest resistance, environmental concerns and increased production costs. In contrast, the integration of digital tools such as artificial intelligence (AI), Internet of Things (IoT), remote sensing, drone technology and decision support systems (DSS) has enabled more precise, real time and sustainable pest management strategies. These innovations allow early detection, spatial monitoring and predictive modelling of pest outbreaks by enhancing the accuracy of interventions and minimizing the use of pesticides. The recent advancements in digital diagnostics, automated pest surveillance, machine learning algorithms for pest forecasting and mobile based advisory platforms are vital in orchard management. Case studies from tropical and subtropical fruit crops are highlighted the potentiality of these tools in improving pest control efficiency and environmental safety. Furthermore, it includes the challenges in technology adoption, data integration and capacity building among the growers. Hence, the digital transformation of IPM represents a paradigm shift towards smart, sustainable and climate resilient pest management in fruit crops production.

Keywords - Digital IPM, artificial intelligence, internet of things, pest forecasting, fruit crops

ZERO-RESIDUE INTEGRATED PEST MANAGEMENT (ZR-IPM)

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ABSTRACT

The concept of *Zero-Residue Integrated Pest Management (ZR-IPM)* represents a transformative advancement in sustainable and organic agriculture, aiming to produce food entirely free from chemical residues while maintaining high crop productivity and ecological balance. Unlike conventional IPM, which primarily focuses on reducing pesticide use, ZR-IPM integrates *biodegradable bioinputs, microbial consortia, botanical formulations, and nano-biocarriers* to ensure complete degradation of active ingredients before harvest. This approach relies on a 4D defense framework — Detection, Decision, Defense, and Degradation — combining real-time pest surveillance through sensors and AI-based predictive tools with threshold-guided application of biopesticides, beneficial microbes, and plant-derived volatiles.Recent innovations such as chitosan-encapsulated neem nanoemulsions, microbial blends of *Trichoderma*, *Beauveria*, and *Bacillus*, and pheromone-based mating disruption systems have demonstrated over 90% pest suppression with undetectable residue levels (<0.01 ppm) in tomato, okra, and cotton trials across India. These eco-safe formulations not only manage pest complexes effectively but also enhance soil microbial activity, crop vigor, and pollinator safety. Furthermore, ZR-IPM aligns with global sustainability goals, addressing consumer demand for residue-free food and meeting stringent export regulations under the EU's "Farm to Fork" strategy and India's "Zero Pesticide Residue" initiatives. By merging organic principles, biotechnology, and digital intelligence, Zero-Residue IPM redefines pest management as an ecologically regenerative and economically viable system. It envisions a future where protecting crops no longer compromises environmental purity or human health — achieving the ideal of *"safe food from a safe ecosystem."*

Keywords: Zero-residue IPM; Biodegradable biopesticides; Nano-biocarriers; Microbial consortia; Botanical formulations; Organic pest management; Sustainable agriculture; Residue-free food; AI-guided pest monitoring; Eco-safe farming.

ADVANCING INTEGRATED PEST MANAGEMENT THROUGH AI AND MACHINE LEARNING INNOVATIONS

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ABSTRACT

The emergence of digital technologies has opened new frontiers in Integrated Pest Management (IPM), offering intelligent, data-driven solutions for sustainable crop protection. This chapter explores how innovations in artificial intelligence (AI), machine learning (ML), and precision agriculture are revolutionizing pest monitoring, forecasting, and control. As agriculture faces growing challenges such as climate variability, pest resistance, and the need to reduce chemical dependence, the integration of these technologies has become essential for ensuring food security and environmental sustainability. Cutting-edge digital tools and algorithms now enable predictive analytics, allowing farmers to anticipate pest outbreaks, assess crop health in real time, and implement timely interventions. Through remote sensing, Internet of Things (IoT) devices, and AI-powered image recognition, farmers can detect pest infestations early and optimize pesticide application with remarkable accuracy. These advancements not only improve pest control efficiency but also promote eco-friendly practices by minimizing input use and environmental impact. The chapter further examines applications such as AI-based pest identification, ML-driven predictive modeling for pest population dynamics, and decision-support systems that assist farmers in choosing effective and targeted IPM strategies. It also highlights the challenges associated with adopting digital IPM—such as data management, technological accessibility, and the need for farmer capacity-building—and emphasizes the importance of ethical and inclusive technology deployment. By exploring these digital frontiers, this chapter provides comprehensive insights into how technology is reshaping IPM into a more precise, proactive, and sustainable system. It concludes by discussing the future potential of integrating advanced digital platforms and collaborative innovation to achieve smarter pest management and resilient agricultural ecosystems.

Key words: Artificial Intelligence (AI), Machine Learning (ML), Digital Tecnologies and pest detection

HARNESSING THE INSECT MICROBIOME: A NEW FRONTIER IN SUSTAINABLE PEST MANAGEMENT

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ABSTRACT

The insect microbiome comprising diverse bacteria, fungi, and symbiotic microorganisms residing in the gut, cuticle, and reproductive organs plays a crucial role in insect physiology, nutrition, and defense. Recent research has revealed that these microbial communities profoundly influence pest behaviour, reproduction, immunity, and resistance to insecticides. Understanding these complex host-microbe interactions opens new ecological avenues for sustainable pest management. Manipulating the insect microbiome through Para transgenesis, probiotic applications, or microbial disruption can alter pest fitness, reduce vector competence, and suppress pest populations without harming non-target organisms. Beneficial microbes can also be engineered to deliver toxins or interfere with pathogen transmission, providing eco-friendly alternatives to chemical pesticides. Integrating microbiome-based strategies with existing Integrated Pest Management (IPM) frameworks enhances precision, sustainability, and long-term pest control efficacy. Although still in its developmental phase, microbiome manipulation represents a frontier innovation that aligns with global goals of environmentally safe and biologically driven pest management.

Keywords: Insect microbiome, paratransgenesis, symbionts, microbial manipulation, eco-friendly pest control, Integrated Pest Management.

CAPSAICIN: A PUNGENT MOLECULE WITH POTENT INSECTICIDAL POTENTIAL

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ABSTRACT

Capsaicin, the primary pungent alkaloid of chilli peppers (Capsicum annuum L.), is becoming recognised as a powerful botanical pesticide with diverse bioactivity. Capsaicin, generated by the plant's innate defence mechanism, functions as an antifeedant, repellant, and neurotoxic agent against a diverse array of insect pests. The principal mechanism of action entails disrupting the insect nervous system by interacting with transient receptor potential (TRP) ion channels and interfering with neurotransmitter signalling, leading to paralysis, decreased feeding, and ultimately death. Moreover, capsaicin influences the hormonal equilibrium and digestive enzyme function in target insects, thereby inhibiting growth and reproduction. Experimental studies have confirmed its efficacy against aphids, whiteflies, thrips, and pests of stored grain, exhibiting low harm to beneficial organisms and the environment. In addition to its insecticidal capabilities, capsaicin demonstrates antioxidant and antibacterial effects, hence enhancing plant health and promoting resistance. Its biodegradable and non-persistent nature presents less risk of bioaccumulation or pesticide resistance, rendering it appropriate for integrated pest management (IPM) and organic farming systems. Modern research emphasises the enhancement of extraction and formulation methodologies, including encapsulation and nanoemulsion techniques, to improve stability, residual efficacy, and field performance. Capsaicin serves as a promising environmentally friendly alternative to synthetic pesticides, in accordance with the global desire for sustainable and safe agricultural protection solutions. Ongoing exploration of its molecular mechanisms and extensive application potential will accelerate its advancement as a dependable natural insecticidal agent.

Key Words: Capsaicin, *Capsicum annuum*, botanical insecticide, pest management, eco-friendly agriculture.

SUN-POWERED GUARDIANS: REDUCING PESTICIDES, SAVING BENEFICIAL INSECTS

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ABSTRACT

Heavy dependence on chemical pesticides in modern agriculture has raised serious concerns, including the development of pest resistance, environmental contamination, and the decline of beneficial insect populations. In response, automated solar-powered light traps offer an environmentally friendly and sustainable alternative for pest management by using renewable solar energy to attract and monitor pests. These traps emit specific light wavelengths to lure nocturnal insects such as *Helicoverpa armigera*, *Spodoptera litura*, and *Aphis craccivora*, which are subsequently captured using mechanical collection methods or trays. Utilizing solar energy allows for continuous, cost-effective operation while reducing reliance on conventional electricity. Field trials across various agro-ecosystems have demonstrated that solar light traps can significantly reduce pest densities and limit crop damage. Farmers implementing these devices have reported a 30–50% decrease in chemical pesticide usage, lowering production costs and preventing harmful residues in soil, water, and harvested crops. Additionally, minimizing pesticide applications supports the survival and recovery of beneficial insects, including ladybird beetles, lacewings, parasitoid wasps, and pollinators, which are essential for maintaining ecological balance. When integrated into Integrated Pest Management (IPM) strategies, solar light traps enable more effective pest control with minimal environmental impact. Overall, the use of automated solar light traps fosters a sustainable pest management approach, promoting biodiversity, conserving natural predators, and supporting organic and climate-resilient agricultural practices. This renewable energy-based technology not only enhances crop productivity and reduces ecological risks but also represents a significant step toward more eco-friendly and sustainable farming systems.

Keywords: Solar light trap, Integrated Pest management, Pesticide reduction, Beneficial insects, Biodiversity, Sustainable agriculture.

HARNESSING NATURE: ECOLOGICAL INNOVATIONS FOR SUSTAINABLE PEST MANAGEMENT

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ABSTRACT

The shift toward sustainable agriculture is driving a wave of ecological innovations aimed at reducing reliance on synthetic pesticides while maintaining crop productivity. These nature based approaches embrace ecological balance and biodiversity, using biological control mechanisms to manage pests in a more harmonious and lasting way. Beneficial organisms such as entomopathogenic fungi, bacteria, parasitoids, and predators are increasingly used to suppress pest outbreaks without harming non-target species or disrupting ecosystems. Complementary tools like bioinoculants, pheromone traps, and botanical extracts further support natural pest suppression while enhancing soil and plant health. Emerging technologies, including nanobiotechnology, precision agriculture, and microbial bioformulations, are improving the stability, delivery, and field performance of these biological agents. When integrated into a broader framework like Integrated Pest Management (IPM), these eco-friendly solutions create a pest control system that is economically viable, environmentally responsible, and socially inclusive. Crucially, farmer engagement, awareness initiatives, and supportive policy environments are essential for scaling these practices globally. By combining traditional ecological wisdom with modern scientific advances, agriculture can build long-term resilience against pests while preserving vital ecosystem services. Ultimately, working with nature rather than against it offers a promising path toward climate-smart, productive, and sustainable farming systems ensuring both food security and environmental health for future generations.

Keywords: Sustainable Pest Management, Ecological innovations, Biological control, Bioinoculants, Biopesticides, Nanobiotechnology, Biodiversity, Integrated Pest Management (IPM), Regenerative agriculture, Environmental sustainability.

ROLE OF METHYL EUGENOL-BASED PHEROMONE TRAPS IN SUSTAINABLE CONTROL OF MANGO FRUIT FLY

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ABSTRACT

A serious pest of mangoes, the mango fruit fly (Bactrocera dorsalis) causes large output losses and presents serious difficulties for export markets because of stringent quarantine regulations. The purpose of this research is to determine how well pheromone trapping, a crucial part of Integrated Pest Management (IPM), works to suppress B. dorsalis populations in mango orchards. Traps based on methyl eugenol were set up at varying densities and observed throughout the fruiting season in order to assess their effects on adult male populations and the degrees of fruit infection that followed. The results showed that, in comparison to untreated control plots, the frequent deployment of pheromone traps considerably decreased fruit fly infestation and captures. In comparison to chemical pesticides, the trapping technique turned out to be sustainable, economical, and environmentally beneficial. These results indicate that pheromone trapping may be a keystone for the sustainable control of mango fruit fly populations when carefully combined with other IPM elements.

Keywords: Sustainable pest management, Methyl eugenol trap, Fruit fly.

INNOVATIVE APPROACHES FOR INTEGRATED PEST MANAGEMENT - A REVIEW

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ABSTRACT

Integrated Pest Management (IPM) is a sustainable, ecosystem-based strategy that integrates biological, cultural, physical, and chemical tools to manage pest populations below economic injury levels while minimizing environmental harm. In recent years, innovative scientific and technological interventions have transformed IPM into a precision-oriented, climate-resilient, and environmentally compatible system. Modern innovations such as molecular and biotechnological tools, smart digital technologies, nano-formulations, and ecological engineering approaches have enhanced pest monitoring, forecasting, and management efficiency. This review highlights major advancements in IPM practices, emphasizing the integration of eco-friendly biocontrol agents, AI-based surveillance, and farmer-centric participatory models that promote sustainable crop protection and biodiversity conservation.

Keywords: Integrated Pest Management, Biocontrol, Biotechnology, Smart Farming, Biopesticides, Precision Agriculture, Climate-Smart IPM

Introduction

Integrated Pest Management (IPM) combines ecological principles and multidisciplinary approaches to suppress pest populations sustainably. Conventional pesticide-based pest control has led to resistance, resurgence, and environmental contamination. Consequently, IPM strategies have evolved to integrate technological innovations that enhance efficiency and sustainability (Kogan, 1998; Dent, 2000). Modern IPM incorporates smart tools, molecular diagnostics, and eco-engineering techniques for early pest detection and targeted management. These innovations strengthen the adaptability of IPM under changing climatic conditions and dynamic pest scenarios.

Eco-Friendly Biological Control

Biological control forms the foundation of IPM by utilizing natural enemies to maintain pest populations at sub-economic levels. The use of parasitoids such as *Encarsia guadeloupae* against *Aleurodicus dispersus* and *Trichogramma spp.* against lepidopteran borers has been well documented (Nagarajan et al., 2023). Advances in mass rearing, habitat manipulation, and conservation biological control have improved the effectiveness of natural enemies. Microbial control agents, including *Beauveria bassiana*, *Metarhizium anisopliae*, and *Bacillus thuringiensis*, are increasingly used in organic and conventional systems. Floral resource provisioning and intercropping with nectar-rich plants enhance the survival and activity of beneficial insects.

Molecular and Biotechnological Tools

Recent breakthroughs in biotechnology have revolutionized pest management. RNA interference (RNAi) offers species-specific pest suppression by silencing essential genes (Baum et al., 2007). Transgenic crops expressing insecticidal proteins from *Bacillus thuringiensis* reduce pesticide use and protect non-target organisms. DNA barcoding and molecular markers enable rapid pest and natural enemy identification, facilitating early warning and management decisions. These technologies enhance precision and reliability in IPM implementation.

Smart and Digital IPM

The integration of digital technologies into IPM enhances pest detection and decision-making. Internet of Things (IoT)-based traps and sensors provide real-time pest monitoring, while drones and unmanned aerial vehicles (UAVs) are employed for crop surveillance and precision pesticide application (Gupta et al., 2021). Artificial intelligence (AI)-driven mobile applications assist farmers in pest diagnosis and control recommendations. Decision Support Systems (DSS) use predictive algorithms and weather-based data to forecast pest outbreaks, promoting timely interventions.

Botanicals and Biopesticides

Plant-derived pesticides and microbial formulations are gaining importance as eco-friendly alternatives to synthetic chemicals. Neem (*Azadirachta indica*), pongamia, and garlic extracts exhibit insecticidal and repellent activities. Nano-formulations enhance stability, bioavailability, and controlled release of active ingredients, improving pest control efficiency (Kumar et al., 2020). Synergistic use of botanicals and microbial biopesticides can improve efficacy while reducing pesticide residues in food and the environment.

Cultural and Agro-Ecological Strategies

Cultural and habitat manipulation techniques form the preventive component of IPM. Push-pull systems integrate repellent intercrops (push) and attractive trap crops (pull) to divert pests (Khan et al., 2016). Crop rotation, mixed cropping, and field sanitation disrupt pest life cycles. Ecological engineering through flowering borders and soil health management enhances the resilience of agroecosystems by favoring beneficial organisms.

Climate-Smart Pest Management

Climate change significantly alters pest population dynamics and distribution. Climate-smart IPM integrates pest forecasting models with real-time weather data to predict outbreaks. Remote sensing and Geographic Information Systems (GIS) enable large-scale pest surveillance and spatial risk assessment (Prasad et al., 2022). Such predictive tools aid in proactive pest control and minimize economic losses.

Community-Based and Policy Innovations

Farmer Field Schools (FFS) and participatory learning approaches empower farmers to make informed pest management decisions. Area-wide IPM programs coordinate pest suppression across landscapes, enhancing effectiveness (Vreysen et al., 2007). Government initiatives promoting biopesticide registration, residue-free produce certification, and integrated extension systems are essential for large-scale adoption of IPM innovations.

Conclusion

Innovative approaches in Integrated Pest Management combine ecological, technological, and participatory methods to ensure sustainable crop protection. The integration of biocontrol agents, biotechnology, digital monitoring, and climate-smart forecasting has significantly strengthened IPM frameworks. Continued research, farmer capacity building, and supportive policies are essential to mainstream these innovations, ensuring reduced pesticide dependency and enhanced agroecosystem resilience.

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INTEGRATED APPROACHES FOR THE CONTROL OF INSECT IN SPICES AND CEREALS

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ABSTRACT

Spices and cereals are essential components of global diets, yet they are highly prone to insect infestation during post-harvest handling, storage and transport. Such infestations result in substantial quantitative and qualitative losses, adversely affecting aroma, colour, nutrient content and overall consumer acceptability. The management of storage insects therefore remains a critical challenge for ensuring food safety and market quality. This paper highlights the recent advances and integrated strategies employed to control insect pests in theses commodities. Preventive measures such as improved sanitation, temperature and humidity regulation and the use of hermetic or modified-atmosphere packaging have proven effective in reducing infestation levels. Physical control techniques including heat and cold treatments, irradiation and controlled atmospheres provide residue free alternatives to conventional fumigants. Biological approaches utilizing parasitoids, entomopathogenic fungi and botanical insecticides offer eco-friendly options with minimal environmental impact. Chemical control methods, particularly phosphine fumigation, remain widely used but require strict regulatory oversight to prevent resistance development and residue accumulation. The integration of nanotechnology based formulations, sensor assisted pest monitoring and predictive modeling further enhances the efficiency of pest management systems. The adoption of an Integrated Pest Management (IPM) framework combining these approaches ensures the sustainable protection of spices and cereals while meeting the demands of food safety and environmental stewardship.

Keywords: Spices, Cereals, Insect infestation, integrated pest management, Post-harvest protection, Bio control, Storage technology.

ASSOCIATION OF ENDOSYMBIONTS WITH *Bemisia tabaci* OF PHYLOGENETICALLY DIFFERENT GROUPS

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ABSTRACT

Begomovirus stanleyi (*Sri Lankan cassava mosaic virus)* is considered as one of the important biotic constrain of the industrial crop cassava (*Manihot esculenta Crantz*). Cassava mosaic disease causes both quantitative and qualitative loss of up to 80 per cent. The virus is transmitted by the insect vector *Bemisia tabaci* (*Gennadius*). *B. tabaci* (*Gennadius*) (*Hemiptera*: *Aleyrodidae*) is an economic pest of important agricultural crops found worldwide. As a vector, it plays a key role in transmission of most of the plant viruses. Different populations of whitefly and its relationship with endosymbionts were studied based on mtCOI (Mitochondrial cytochrome oxidase), ITS region and RAPD analysis. Two different genotypes such as Q genotype and B genotype were identified from different crops cultivated in Tamil Nadu. The association of endosymbionts such as *Rickettsia* sp, *Arsenophonus* sp and *Wolbachia* sp with the whitefly biotypes were also studied. The endosymbionts were found to play major role in increasing the survival ability and virulence of the vector. Transmission efficiency of *Bemisia tabaci* was also studied and the inoculation feeding period for the SLCMV transmission was recorded to be 24 hrs (one day).

Keywords: *Bemisia tabaci,* genotype of whitefly, endosymbionts, transmission efficiency.

STUDIES ON NUTRITIONAL OPTIMIZATION FOR MYCELIAL GROWTH AND BIOMASS ENHANCEMENT OF ENTOMOPATHOGENIC FUNGI *Ophiocordyceps sinensis*

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ABSTRACT

Ophiocordyceps sinensis (formerly *Cordyceps sinensis*), an entomopathogenic fungus commonly known as the Chinese caterpillar fungus, is highly valued in traditional Chinese medicine due to its production of bioactive metabolites with significant pharmaceutical importance. However, its cultivation requires a variety of nutritional components to achieve rapid growth, high biomass yield, and successful fruiting body formation. In this context, a study was conducted to evaluate the effects of different carbon, nitrogen, mineral, vitamin, and chitin sources on the growth and biomass production of O. sinensis under liquid fermentation conditions. Among the tested nutrients, sucrose (3%) and beef extract (0.5%) supported the highest mycelial growth and biomass accumulation (90.00 mm colony diameter and 8.13–8.17 g dry weight/L after 18 days). The best-performing mineral sources were K_2HPO_4 and zinc chloride (0.2%), which promoted comparable growth and biomass yield (90.00 mm and 8.12–8.20 g/L on the 18th day). Furthermore, supplementation with folic acid (0.01%) and dried rhinoceros grub powder (0.1%) significantly enhanced mycelial development, resulting in the highest biomass production (90.00 mm and 8.31–8.69 g/L after 18 days). This study emphasises the significance of nutritional optimisation in enhancing mycelial growth, biomass accumulation, metabolite secretion, and potential fruiting induction in *O. sinensis* under controlled fermentation conditions.

Keywords: Entomopathogenic fungi, Biomass, *Ophiocordyceps sinensis*, mycelial growth and fermentation

INFLUENCE OF LIGHT SOURCES ON SPORULATION OF *Colletotrichum capsici*

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ABSTRACT

Turmeric is a most cultivated spice crop and is cherished for its aroma, taste and oleoresin content and used as herbal medicine and colouring powder for textile industry. India is the world largest producer of turmeric, followed by China, Indonesia, Bangladesh and Thailand. It occupies about six per cent of the total area under spices and condiments in India. The main turmeric producing states in India are Andhra Pradesh, Tamil Nadu, Orissa, Karnataka, West Bengal, Gujarat and Kerala. As a major crop, which is infected by several diseases *viz.,* rhizome rot, leaf spot and leaf blotch. Leaf spot incited by *Colletotrichum capsici* [Sydow (Butler & Bisby)] in turmeric is highly destructive causing yield loss up to 62 per cent with reduction in quality. Turmeric leaves showed typical leaf spot symptoms were collected and pathogen was isolated from the lesions. The effect of light on growth and sporulation of *C. capsici* was studied on potato dextrose agar by exposing the pure cultures in Petri plate to 12 h. dark + 12 h. light, 6 h. dark + 18 h. light, 3 h. dark + 21 h. light, 18 h. dark + 6 h. light dark and 21 h. dark + 3 h. light. The plates were incubated at 28±1°C for seven days at continuous dark by covering with aluminium foil. The control plates were kept under natural light and dark conditions without covering aluminium foil. Observations on colony diameter and sporulation were recorded. *C. capsici* showed the excellent conidia production under 3 h. dark + 21 h. light and continuous dark for seven days and the good sporulation was recorded in 6 h. dark + 18 h. light and continuous dark for seven days. Poor conidia production was observed in 21 h. dark + 3 h. light and continuous dark for seven days.

Key words: Turmeric Leaf spot, *Colletotrichum capsici,* Sporulation.

ECO-FRIENDLY SUPPRESSION OF GUAVA WHITEFLY THROUGH BIOLOGICAL CONTROL AGENTS WITHIN AN IPM STRATEGY

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ABSTRACT

Guava (*Psidium guajava* L.) production is being affected by whitefly (*Dialeurodes citri*) infestations, a serious pest that causes severe damage by sucking sap and encouraging the growth of sooty mildew. This study assesses the efficacy of biological management employing natural enemies predators and parasitoids as a key component of Integrated Pest Management (IPM) for long-term whitefly suppression. Field trials were conducted in guava orchards to examine the impact of releasing major natural enemies, such as the green lacewing (*Chrysoperla carnea*), a predator, and (*Encarsia guadeloupae)*, a parasite. Regular monitoring revealed significant reductions in whitefly populations in treated plots compared to untreated controls. To maximize the impact of predator and parasitoid releases, they were timed to coincide with peak whitefly populations. The findings showed that whitefly populations below economic threshold levels can be successfully managed by biological management alone, without the use of chemical interventions. Additionally, there was a decrease in the comeback of pests and the preservation of native beneficial insects. This study backs the use of parasitoids and predators as a practical, environmentally responsible method of managing whiteflies in guava, which is consistent with IPM and sustainable agriculture.

Keywords: Guava whitefly, Biological control, Integrated Pest Management (IPM), Natural enemies, Eco-friendly pest control

FIELD EVALUATION OF T*richogramma chilonis* AND *Chrysoperla carnea* FOR THE BIOLOGICAL CONTROL OF *Helicoverpa armigera* IN TOMATO

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ABSTRACT

Tomato (*Solanum lycopersicum* L.) is a widely cultivated crop prone to infestation by the fruit borer, *Helicoverpa armigera*, a major pest that causes substantial yield and economic losses. This study evaluates the effectiveness of two biological control agents—*Trichogramma chilonis* (egg parasitoid) and *Chrysoperla carnea* (predator of early larval stages)—as key components of an Integrated Pest Management (IPM) strategy for managing *H. armigera* in tomato cultivation. Field experiments involved periodic releases of *T. chilonis* to parasitize eggs and reduce larval emergence, complemented by releases of *C. carnea* to prey on surviving early instar larvae. Monitoring results indicated a significant decrease in pest population and fruit damage in biologically treated plots compared to untreated controls. The combined use of these natural enemies maintained pest levels below the economic threshold and reduced the reliance on chemical insecticides. Furthermore, the conservation of other beneficial arthropods and improved fruit quality were observed in IPM-managed fields. These findings support the integration of both *T. chilonis* and *C. carnea* into a sustainable, eco-friendly IPM program for effective control of *H. armigera* in tomato ecosystems.

Keywords: Tomato fruit borer, Biological control,Integrated Pest Management (IPM),Egg parasitoid,Predator

ENHANCING ANTIXENOSIS-MEDIATED RESISTANCE TO YELLOW STEM BORER (*Scirpophaga incertulas* WALKER) THROUGH INTERCROPPING AND BORDER CROP STRATEGIES IN IRRIGATED RICE ECOSYSTEMS

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ABSTRACT

The yellow stem borer (*Scirpophaga incertulas* Walker) remains one of the most destructive pests of irrigated rice (*Oryza sativa* L.) across South and Southeast Asia, causing considerable yield losses. Continuous reliance on chemical insecticides has led to pest resurgence, resistance, and environmental degradation. To address these challenges, the present research focused on exploring host plant resistance, particularly antixenosis (non-preference), as an eco-friendly mechanism for pest suppression. The study was carried out during 2024–2025 at SRM Valliammai Engineering College, Kattankulathur, to evaluate the influence of intercropping and border crops on enhancing antixenosis-mediated protection against the yellow stem borer in irrigated rice systems. A Randomized Block Design (RBD) was adopted with the rice variety Co51 as the main crop, intercropped with sesame (*Sesamum indicum*), cowpea (*Vigna unguiculata*) and marigold (*Tagetes erecta*) and bordered with repellent crops such as maize (*Zea mays*) and sorghum (*Sorghum bicolor*). Observations on pest parameters, including the number of egg masses per hill, dead hearts, whiteheads, larval incidence, and grain yield, were recorded at key crop growth stages. Behavioral observations of oviposition preference and adult moth activity were also conducted to assess non-preference dynamics. The results revealed that rice plots intercropped with marigold + bordered with maize exhibited the lowest oviposition rate and larval incidence, recording a 42.8% reduction in dead hearts and 36.5% higher yield compared to the monocrop control. The sesame intercrop with sorghum border also demonstrated a strong deterrent effect, confirming that visual and olfactory interference from intercrops and border plants can disrupt the pest's host-location behaviour. Statistical analysis (ANOVA) indicated significant treatment differences at $p \leq 0.05$ for all recorded parameters. Overall, the experiment demonstrated that specific combinations of intercrops and border crops can effectively enhance antixenosis expression in rice, thereby reducing pest pressure and pesticide dependence. The study provides a promising framework for developing ecological engineering-based Integrated Pest Management (IPM) models tailored for Tamil Nadu's irrigated rice ecosystems. The outcomes align with India's sustainable agriculture goals by promoting biodiversity-friendly, low-chemical, and climate-resilient rice cultivation systems.

Keywords: Rice, yellow stem borer, Antixenosis, inter-crop and Pest Management

Introduction

Rice (*Oryza sativa* L.) sustains more than half the global population. In South and Southeast Asia, *Scirpophaga incertulas* Walker (yellow stem borer, YSB) remains a persistent pest, causing yield losses up to 30–40% (Balaji et al., 2025). Conventional control through insecticides such as chlorantraniliprole and fipronil provides temporary relief but contributes to resistance, pest resurgence, and biodiversity loss (Patel et al., 2025).

Host plant resistance, particularly antixenosis, is a promising avenue within Integrated Pest Management (IPM). Antixenosis involves deterring pest colonization or oviposition through visual or chemical cues, thereby preventing initial infestation. Border crops and intercrops can further enhance antixenosis by disrupting pest orientation and host-seeking behavior (Nayak & Das, 2021). Despite progress in varietal resistance screening, there is limited research combining intercropping and border cropping for YSB suppression in irrigated rice ecosystems. This study hypothesized that appropriate crop combinations could synergistically enhance antixenosis-mediated resistance while maintaining or improving yield.

Genotypic variation in rice for resistance to YSB has been extensively reported. Balaji et al. (2025) identified several moderately resistant landraces with reduced dead-heart and white-head incidence under field conditions. Shai Prasanna and Joshi (2024a, 2024b) demonstrated that resistance is controlled by complementary gene action, suggesting potential for combining resistance and yield through breeding.

Eco-friendly management alternatives are gaining traction. Baliyan et al. (2025) reported that biopesticides and botanicals such as *Metarhizium anisopliae* and neem-based formulations were effective against YSB. Patel et al. (2025) found that seedling root-dip treatments using thiamethoxam and chlorantraniliprole significantly reduced infestation levels with minimal residue accumulation. Intercropping and border cropping have shown success in managing other rice pests by creating habitat diversification and disrupting pest host-finding cues (Nayak & Das, 2021). However, limited empirical evidence exists for their integration with antixenosis-based mechanisms in YSB management. This study bridges that gap by evaluating border and intercropping combinations that may modify pest behavior through ecological interference. Based on that the following objectives were prepared.

1. To evaluate intercropping and border crop combinations for antixenosis-mediated resistance against YSB.
2. To quantify pest incidence, oviposition preference, and yield under various crop combinations.
3. To develop an ecological engineering-based IPM model suitable for Tamil Nadu's irrigated rice ecosystems.

Materials and Methods

Experimental Site

The experiment was conducted during the 2024–2025 *kharif* season at SRM Valliammai Engineering College, Kattankulathur, Tamil Nadu (12°44′N, 80°00′E). The site is characterized by a tropical climate with an average temperature of 30.5°C and annual rainfall of 1150 mm.

Experimental Design

A Randomized Block Design (RBD) with six treatments and three replications was adopted.

Table 1. Treatment details

Treatment Code	Cropping Pattern	Border Crop	Intercrop
T_1	Rice (Co51) monocrop	None	None
T_2	Rice + Sesame	None	Sesame (*Sesamum indicum*)

Treatment Code	Cropping Pattern	Border Crop	Intercrop
T_3	Rice + Cowpea	None	Cowpea (*Vigna unguiculata*)
T_4	Rice + Marigold	None	Marigold (*Tagetes erecta*)
T_5	Rice + Marigold	Maize (*Zea mays*)	Marigold
T_6	Rice + Sesame	Sorghum (*Sorghum bicolor*)	Sesame

Crop Establishment

Seedlings of rice (Co51) were transplanted at 25 × 25 cm spacing in 4 × 4 m plots. Border crops were sown two weeks prior to rice transplanting to ensure canopy establishment. Standard agronomic practices were maintained uniformly across treatments.

Data Collection

Pest parameters were recorded at 30, 60, and 90 DAT (days after transplanting):

- Number of egg masses per 10 hills
- Dead hearts (%) at vegetative stage
- White heads (%) at maturity
- Grain yield (t ha^{-1})
- Behavioral observations included moth landing frequency and oviposition counts under field conditions using visual scoring at dusk (18:00–20:00 hrs).

Statistical Analysis

Data were subjected to ANOVA using SAS v9.4. Means were compared by Tukey's HSD ($p \leq 0.05$). Percentage data were arcsine-transformed prior to analysis.

Results

The results of the present investigation revealed significant variations among the different intercropping and border crop treatments in suppressing yellow stem borer incidence and enhancing rice yield.

Table 2 presents the influence of various intercropping and border cropping treatments on the incidence of yellow stem borer (YSB) and grain yield in irrigated rice. Significant reductions in both dead-heart and white-head percentages were observed across all diversified cropping treatments compared to the monocrop control (T_1). The rice monocrop (T_1) exhibited the highest pest incidence, with 9.8% dead hearts and 14.5% white heads, reflecting the vulnerability of a uniform cropping system to pest attack. Intercropping rice with sesame (T_2) resulted in a noticeable reduction in pest infestation, recording 7.2% dead hearts and 10.8% white heads. Similarly, the rice + cowpea treatment (T_3) further lowered infestation to 6.9% dead hearts and 9.6% white heads, suggesting moderate deterrence.

The rice + marigold combination (T_4) performed better, reducing dead hearts to 6.0% and white heads to 8.1%, which demonstrates marigold's repellency against YSB adults. Among all treatments, the marigold + maize border (T_5) was most effective, recording the lowest pest incidence of 5.6% dead hearts and 8.3% white heads. This treatment also achieved the highest grain yield (6.99 t ha^{-1}), corresponding to a 36.5% increase over the monocrop. The sesame + sorghum border combination (T_6) also provided strong protection, limiting dead hearts to 5.9% and white heads to 9.1%, with a yield of 6.72 t ha^{-1} (31.3% gain). The observed reductions in pest infestation indicate that both visual and olfactory cues from intercrops and border crops disrupt the pest's host-finding behavior. Treatments involving non-host species such as maize and sorghum appeared to act as physical and sensory barriers to adult moth movement and oviposition. The improved yields under diversified systems further suggest that pest suppression directly translated into higher productivity without compromising crop health. Statistical analysis (ANOVA) confirmed that treatment differences were significant ($p \leq 0.05$) for all parameters recorded. The consistency of the trend across replications implies that the effect of intercropping and border cropping is reliable and reproducible under field conditions. Overall, Table 2 clearly demonstrates that strategic combinations of intercrops and border crops can enhance antixenosis-mediated resistance in rice, effectively minimizing pest damage and improving yield performance.

Table 2. Effect of intercropping and border cropping on yellow stem borer incidence and yield

Treatment	**Dead hearts (%)**	**White heads (%)**	**Yield (t ha^{-1})**	**Yield increase over control (%)**
T_1 – Rice monocrop	9.8	14.5	5.12	–
T_2 – Rice + Sesame	7.2	10.8	5.78	12.9
T_3 – Rice + Cowpea	6.9	9.6	5.85	14.3
T_4 – Rice + Marigold	6.0	8.1	6.21	21.3
T_5 – Rice + Marigold + Maize border	5.6	8.3	6.99	36.5
T_6 – Rice + Sesame + Sorghum border	5.9	9.1	6.72	31.3

Figure 1. *Relative reduction (%) in dead-heart and white-head incidence in rice under different intercropping and border crop combinations compared to monocrop control.*

(Editable description: A clustered bar chart comparing each treatment (T_1–T_6) on two axes—Dead hearts % and White heads %. The highest reduction is seen in T_5 (marigold + maize border), followed by T_6 (sesame + sorghum). Error bars represent ±SE of means.)

Discussion

Intercropping and border cropping significantly reduced YSB infestation, supporting the hypothesis that habitat diversification enhances antixenosis. The marigold + maize combination (T_5) recorded the lowest oviposition and highest yield. The reduction in dead hearts (42.8%) and increase in yield (36.5%) indicate a strong deterrence effect, likely mediated through visual contrast and volatile emissions that disrupt pest orientation.

These findings align with ecological engineering principles and previous studies demonstrating that plant diversity influences pest population dynamics (Baliyan et al., 2025). Similarly, Nayak and Das (2021) reported lower YSB incidence in farmer fields adopting non-host border crops. The study demonstrates that behavioral manipulation through plant spatial arrangement can complement genetic resistance. However, broader evaluation across seasons and sites is necessary to validate these results. Adoption of such IPM modules could reduce pesticide reliance by up to 40%, promoting biodiversity and sustainability in irrigated rice ecosystems.

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ECO-FRIENDLY PEST MANAGEMENT THROUGH DRIP IRRIGATION: A SUSTAINABLE APPROACH

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ABSTRACT

Pest control remains one of the most critical challenges in agriculture, often leading to significant crop losses and financial burdens for farmers. Traditional pest control methods, particularly the use of chemical pesticides, have shown limited effectiveness and have caused substantial harm to the environment, including the destruction of beneficial insect populations. This paper explores the role of drip irrigation as a modern, sustainable alternative that not only conserves water but also aids in effective pest control. Drip irrigation delivers water directly to the root zones of plants, minimizing moisture on plant surfaces and surrounding soil, thus creating an unfavorable environment for many common pests. Through a process known as fertigation, water-soluble pesticides and organic pest control agents can be delivered precisely to targeted areas, improving efficiency while reducing chemical usage. The system proves especially beneficial against soil-borne pests such as root aphids, nematodes, and fungus gnats, and also contributes to reducing populations of whiteflies, aphids, slugs, snails, and mosquitoes by altering environmental conditions necessary for their survival. Moreover, drip irrigation limits weed growth, indirectly reducing pest habitats, and contributes to healthier crops with increased pest resistance. The method, while not directly impacting canopy-level pests like caterpillars or beetles, enhances plant resilience, thereby supporting natural pest defense mechanisms. Combined with Integrated Pest Management (IPM) strategies, drip irrigation emerges as a powerful, eco-friendly solution that balances productivity with environmental responsibility. This approach offers farmers a sustainable method for pest control, addressing critical concerns such as water scarcity, environmental degradation, and long-term soil health, while promoting biodiversity and ecological balance in agricultural ecosystems.

Keywords: Drip Irrigation, Pest Control, Sustainable Agriculture

BIOLOGY AND DEVELOPMENT OF THE BLACK SOLDIER FLY (*Hermetia illucens* L.) REARED ON ORGANIC WASTE

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ABSTRACT

The black soldier fly (*Hermetia illucens* L.) has emerged as a valuable insect species due to its ecological role in bioconversion of organic waste and potential as a protein source for feed industries. The present study was carried out to document the complete biology of the black soldier fly under controlled laboratory conditions in SRM College of agricultural sciences Baburayanpettai, Chennai, Tamil Nadu. Adult lifespan averaged 10–12 days, with females laying 480 ± 15 eggs per batch at 30 ± 1 °C and 75 ± 5 % RH. Egg incubation period lasted 4.8 ± 0.2 days, and larval duration averaged 19.6 ± 1.1 days, followed by a pupal stage of 15.2 ± 0.9 days. Using Dyar's rule, five larval instars were identified with mean lengths of 2.3, 6.2, 10.5, 15.6, and 17.1 mm, respectively. Adults exhibited positive phototaxis and humidity-dependent oviposition, while larvae showed strong olfactory responses toward decomposing organic matter. The entire lifecycle from egg to adult averaged 57 ± 2.5 days. Results indicate that *H. illucens* can be efficiently cultured under tropical Indian conditions, facilitating sustainable organic waste management and feed resource development.

Keywords: Black soldier fly, *Hermetia illucens*, biology, larval instars, organic waste, life cycle

INTRODUCTION

The growing global emphasis on sustainable waste management and alternative protein sources has revived interest in insects, particularly the black soldier fly (*Hermetia illucens*), for its multifaceted utility (Tomberlin and Sheppard, 2002). Waste accumulation in urban and peri-urban regions of India presents severe environmental challenges (FAO, 2023). Traditional composting and biogas production, while effective, are space- and cost-intensive.

The larvae of *H. illucens* feed voraciously on decomposing organic matter such as vegetable residues, manure, and food waste, converting it into high-value biomass rich in proteins (40–45%) and lipids (25–35%) (Zhang et al., 2010). The adult flies are non-pestiferous, non-feeding, and harmless to humans and livestock, making them suitable for controlled insect farming systems.

Previous research has mostly focused on waste reduction efficiency and larval feed utilization, while studies on complete biological parameters under tropical Indian conditions are scarce. Therefore, the present study was conducted to elucidate the life cycle, developmental stages, and morphological features of *H. illucens* under laboratory conditions at SRM College of Agricultural Sciences, Baburayanpettai .

MATERIALS AND METHODS

Study Site

The experiment was conducted during January–April 2025 in the insectary of the Department of Agricultural Entomology, SRM College of Agricultural Sciences, Baburayanpettai (12.3845° N, 79.7352° E) Ambient laboratory conditions were maintained at 30 ± 1 °C temperature, relative humidity 70–80 %, and 12L:12D photoperiod throughout the experimental period.

Culture Initiation

Adult black soldier flies were collected from compost heaps within the campus. They were maintained in mesh cages (60 × 60 × 60 cm) provided with moistened sponges as water sources and corrugated cardboard strips for oviposition. Egg clutches were transferred to plastic trays (40 × 30 × 15 cm) containing pre-fermented kitchen waste (vegetable peels, fruit residues, and bran).

Larval Rearing

Larvae were reared on 1 kg of homogenized food waste per tray, mixed with 100 g wheat bran to maintain consistency. The substrate was replaced every 3 days. Larval lengths were measured every 3 days using digital calipers.

Pupal and Adult Rearing

Mature larvae were separated at the pre-pupal stage by self-harvesting ramps and transferred to containers with moist soil for pupation. Newly emerged adults were sexed by

external morphology (antennae and genitalia) and maintained for mating in cages under natural light.

Morphometric and Developmental Observations

Eggs, larvae, pupae, and adults were measured for length, width, and weight. The number of larval instars was determined using Dyar's law (Dyar, 1890). Oviposition, fecundity, incubation, and longevity were recorded through daily observations.

Statistical Analysis

All parameters were subjected to descriptive statistical analysis (mean ± SD). Environmental influences were noted qualitatively.

RESULTS AND DISCUSSION

Oviposition and Egg Morphology

Females began oviposition 6–7 days post-emergence and deposited clusters of 480 ± 15 eggs in crevices and cardboard folds near decomposing waste. Eggs were elongate, creamy white, and measured 0.90 ± 0.02 mm in length. Incubation required 4–5 days at 30 °C and 75 % RH, similar to reports by Sivanantharaja and Gnaneswaran (2018) from Sri Lanka.

Larval Development

Five distinct larval instars were recognized by mouth hook length and body segmentation (Table 1). The total larval period lasted 19.6 ± 1.1 days, and larvae displayed vigorous surface feeding behavior.

Table 1. Morphometric data of *H. illucens* larvae at different instars

Instars	Mean Length (mm) ± SD	Mean Width (mm) ± SD	Duration (days) ± SD

I	2.3 ± 0.03	0.4 ± 0.02	2.0 ± 0.1
II	6.2 ± 0.06	1.1 ± 0.03	3.0 ± 0.2
III	10.5 ± 0.08	2.1 ± 0.04	4.0 ± 0.3
IV	15.6 ± 0.10	3.1 ± 0.05	5.0 ± 0.4
V	17.1 ± 0.12	3.4 ± 0.05	5.6 ± 0.3

Larvae changed from creamy white to light brown as they matured. Feeding activity ceased at the pre-pupal stage, during which larvae turned dark brown and migrated away from moist areas seeking drier substrate for pupation.

Pupal and Adult Stages

The pupal period lasted 15.2 ± 0.9 days, with pupae measuring 17.2 ± 0.1 mm in length. Adult emergence occurred synchronously after 30–32 days from oviposition. Adults were wasp-like, black with translucent abdominal segments and non-functional mouthparts.

Mean adult lifespan was 10.6 ± 0.4 days, with females surviving slightly longer than males. Mean wingspan was 12.3 ± 0.2 mm (male) and 13.0 ± 0.2 mm (female).

Table 2. Summary of biological parameters of *H. illucens*

Parameter	Range	Mean ± SD
Egg period (days)	4–5	4.8 ± 0.2
Larval period (days)	18–22	19.6 ± 1.1
Pupal period (days)	13–17	15.2 ± 0.9
Adult longevity (days)	9–12	10.6 ± 0.4
Fecundity (eggs/female)	460–500	480 ± 15
Total life cycle (days)	55–59	57 ± 2.5

Feeding and Behavioral Observations

Larvae actively decomposed organic residues, producing nutrient-rich residue (frass). They preferred moist substrates with a moderate decomposition odor, confirming olfactory-driven feeding (Zhang et al., 2010). Adults were strongly phototactic and humidity-dependent; lack of moisture led to reduced mating activity.

Overall, the developmental duration and morphology observed under Chennai's tropical conditions were consistent with previous global reports (Sheppard et al., 2002; Tomberlin et al., 2009), validating the adaptability of *H. illucens* to Indian climates.

CONCLUSION

The black soldier fly completes its entire life cycle in about 57 days under tropical laboratory conditions in Chennai. The species shows high fecundity, rapid larval growth, and effective waste reduction potential. These findings confirm that *Hermetia illucens* can be efficiently mass-reared in Indian environments, supporting sustainable organic waste management and insect-based protein production initiatives.

ACKNOWLEDGEMENT

The author expresses sincere gratitude to the Department of Agricultural Entomology, SRM College of Agricultural Sciences, SRM institute of Science and Technology, for providing necessary facilities and technical assistance during the study.

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IMAGE PROCESSING FOR HIGH-DENSITY MANGO FARMING: DETECTION OF PLANT DISEASE AND FRUIT GRADING

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ABSTRACT

High-density mango farming provides a promising pathway to boost agricultural productivity but brings new challenges in monitoring plant health and maintaining fruit quality. This study aims to develop an intelligent image processing system for automated disease detection and fruit grading in mango cultivation. The proposed approach integrates drone-based and ground-level imaging with machine learning techniques to support farmers in making informed decisions. A comprehensive image dataset will be collected, covering both healthy and diseased plants and fruits at various ripeness stages. Image pre-processing methods will be applied to improve clarity and contrast, enabling precise feature extraction. Convolutional Neural Networks (CNNs) will be trained to detect and classify plant diseases, while segmentation techniques will isolate affected regions for accurate diagnosis. Fruit grading will utilize color, size, and texture features, which are processed through machine learning classifiers to categorize mangoes into quality grades. Field experiments will assess the accuracy, precision, and recall of the models, ensuring reliable real-time performance. Additionally, a farmer-friendly application will be developed to provide instant disease alerts and grading reports. The expected benefits include early disease detection, improved grading consistency, reduced post-harvest losses, and higher market value. This research highlights the potential of integrating image processing and AI technologies to support sustainable high-density mango farming, ensuring better yield, profitability, and quality assurance.

Keywords: Image Processing, High-Density Mango Farming, Plant Disease Detection, Fruit Grading, Machine Learning, CNN, Precision Agriculture, Sustainable Farming.

ECO-INTELLIGENT TRAP CROPPING: A SUSTAINABLE APPROACH TO SMART PEST MANAGEMENT

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ABSTRACT

Eco-intelligent trap cropping, a time-tested ecological approach, is gaining renewed importance as a sustainable component of Integrated Pest Management (IPM). This strategy utilizes specific crops that are more attractive to insect pests than the main crop, thereby diverting pest populations and reducing crop damage. Beyond simple pest diversion, eco-intelligent cropping systems integrate ecological principles and precision agronomy to enhance system resilience, conserve natural enemies, and minimize pesticide dependence. The effectiveness of trap crops within an eco-intelligent framework depends on their inherent characteristics, pest behaviour, spatial arrangement, and synchronization with the main crop. Studies have shown that crops like squash around tomato or cantaloupe around cotton effectively attract pests such as whiteflies, lowering infestation and virus incidence. Moreover, eco-intelligent trap cropping provides multiple ecological services such as supporting natural enemy populations and improving agro-ecosystem stability. The success of these systems lies in their knowledge-intensive design, considering crop–pest interactions and local agro-climatic factors. By combining traditional ecological wisdom with modern precision techniques, eco-intelligent trap cropping emerges as a promising, smart, and sustainable solution to pest management, aligning with the goals of climate-resilient and environmentally responsible agriculture.

Keywords: Eco-intelligent cropping, Trap crops, Sustainable pest management, Pest diversion, Ecological resilience

SMART FARMING FRONTIERS: PRECISION AGRICULTURE MEETS INTEGRATED PEST MANAGEMENT

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ABSTRACT

The increasing global population has intensified the necessity for sustainable and efficient agricultural practices. One promising avenue for meeting this demand is the synergy between Precision Agriculture (PA) and Integrated Pest Management (IPM). This aims to scrutinize the multifaceted relationship between PA and IPM in augmenting crop protection and yield. Utilizing a comprehensive analysis of existing literature, the study elucidates how cutting-edge technologies in PA, such as drone imaging and soil sensor networks, can be harmoniously integrated with IPM strategies. These encompass biological, chemical, and cultural tactics to manage pest populations and mitigate damage, thereby fostering an environment conducive to optimal crop growth. The review identifies that the confluence of PA and IPM not only enhances the efficiency of resource use but also mitigates the environmental footprint of agricultural activities. Moreover, we delve into case studies that demonstrate significant yield improvements and cost reductions, underscoring the economic viability of integrating PA and IPM. The findings highlight the transformative potential of marrying these two domains, suggesting that such integration could be a cornerstone in the future of sustainable agriculture. The paper concludes by outlining research gaps and proposing avenues for future studies, emphasizing the need for multi-disciplinary approaches to fully unlock the potential of this integration.

Keywords: Agronomic crops; crop protection; integrated pest management (IPM); precision agriculture (PA); sustainable agriculture; technological innovations.

ADVANCING PEST CONTROL THROUGH RNAi GENE SILENCING

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ABSTRACT

The hunt for creative pest management techniques that reduce the use of chemical pesticides and save the environment has been fueled by the growing demand for sustainable agriculture practices. By precisely silencing vital genes needed for an insect's development, reproduction, or survival, RNA interference (RNAi) technology has become a potent and environmentally safe technique for controlling insect pests. A naturally occurring, highly conserved biological process called RNA interference (RNAi) uses short double-stranded RNA (dsRNA) molecules to control gene expression by causing complementary messenger RNA (mRNA) to degrade. RNA interference (RNAi) provides a tailored method to pest management, guaranteeing that beneficial organisms remain unaffected while only the targeted pest species are impacted. Through a variety of techniques, including feeding, spraying, or plant-mediated expression, dsRNA is delivered as part of the process. The RNA-induced silencing complex (RISC) recognizes the dsRNA once it is inside the cell and directs the destruction of particular mRNAs, upsetting critical physiological circuits. With little ecological disturbance, pest populations are suppressed as a result of this process. For instance, RNAi-based tactics have been effective in combating significant pests such as aphids, cotton bollworms, and western corn rootworms. The stability of dsRNA in the environment, efficient transport to target tissues, and variation in RNAi response across insect groups are some of the obstacles that RNAi technology must overcome despite its potential. Through better formulation methods, more comprehension of insect RNAi machinery, and sophisticated nanoparticle carriers, ongoing research seeks to overcome these constraints. A new generation of economically and environmentally sound precision pest control systems may result from combining RNAi with conventional pest management techniques

Keywords: RNA interference, gene silencing, sustainable pest management, dsRNA, environmentally safe control

PLANT-DERIVED BIOFUMIGANTS: A SAFER AND SUSTAINABLE ALTERNATIVE FOR STORED PEST MANAGEMENT

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ABSTRACT

Stored grain loss caused by insect pests is a significant issue in post-harvest storage. It is being overcome using synthetic fumigants, which cause greater risk to human health and the environment, and many insects have developed resistance. With the aim of minimising it in a more eco-friendly way, plant extracts are gaining attention. Certain medicinal and aromatic plants that have insecticidal properties can be used as a safer alternative to prevent this storage loss. For instance, Compounds like 4-nonanone, linalool, isopulegol 1, caryophyllene oxide, alpha-cadinol, 4,11,11-trimethyl-8-methylene-bicyclo[7.2.0]undec-4-ene in *Cymbopogon citratus* and isopulegal 1, methyl linolenate, aromandendrene, (-)-globulol, rosifoliol, caryophyllene-(i1), 3-octen-5-yne, 2,7-dimethyl-, (z)-, hedycaryol, 3-cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)- in *Eucalyptus tereticornis* are known to possess insecticidal properties. These compounds have the potential to act as biofumigants, an eco-friendly and sustainable alternative for stored pest management.

Keywords: Stored pest management, Synthetic fumigants, Biofumigants, sustainable alternatives.

BLACK SOLDIER FLY LARVAE MEAL: ALTERNATIVE DIETARY PROTEIN SOURCES FOR THE CHICKEN

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ABSTRACT

India's poultry sector is witnessing robust growth, with an annual expansion rate of over 8%, driven by rising demand for affordable animal protein and increasing per capita consumption. Protein is a critical component in poultry diets, essential for muscle development, immune function, and optimal production performance. However, the escalating cost and inconsistent availability of conventional protein sources like soybean meal have prompted the search for sustainable and cost-effective alternatives. Black Soldier Fly Larvae (BSFL) meal emerges as a promising substitute, offering a crude protein content ranging from 40% to 55%, depending on processing methods and substrate. Studies suggest that BSFL meal can be safely included in poultry diets at levels ranging from 5% to 25%, depending on the species and production stage.BSFL can be mass-produced using organic waste streams such as food scraps, poultry litter, and agro-industrial by-products, making it both economical and environmentally friendly. The larvae are harvested, dried, and processed into meal, oil, or powder forms suitable for feed formulation. Incorporating BSFL in poultry diets has shown to improve feed conversion ratio (FCR), enhance growth rates in broilers, and increase egg production and shell quality in layers. Additionally, its antimicrobial peptides contribute to gut health, while its production supports circular bioeconomy through effective waste valorization. The rearing process requires minimal land and water, making it ideal for decentralized, low-cost protein production.

Keywords: Black Soldier Fly, Larvae Meal, Alternative Dietary, Protein, Chicken

APHID MECHANISM OF RESISTANT IN GROUNDNUT GENOTYPES

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ABSTRACT

Aphid infestation (*Aphis craccivora* Koch) is a major constraint in groundnut (*Arachis hypogaea* L.) production, causing direct feeding damage and transmitting peanut stripe and rosette viruses. Understanding the mechanisms of resistance among groundnut genotypes is crucial for developing sustainable pest management strategies. The present study investigates the morphological, biochemical, and molecular bases of aphid resistance in selected groundnut genotypes. Resistant genotypes exhibited lower aphid populations and slower multiplication rates compared to susceptible ones. Morphological traits such as higher trichome density, thicker epidermal layers, and harder pod shells contributed to antixenosis and antibiosis effects. Biochemical analyses revealed elevated levels of phenolic compounds, tannins, and defensive enzymes (peroxidase, polyphenol oxidase, and catalase) in resistant lines, which deter aphid feeding and reproduction. Additionally, certain genotypes demonstrated tolerance through rapid recovery and maintenance of photosynthetic efficiency under infestation. The study highlights the combined action of morphological and biochemical defenses as key determinants of resistance, providing valuable insights for breeding programs aimed at developing aphid-resistant groundnut cultivars.

Keywords: Aphid, Mechanism of Resistant, Groundnut, Genotypes, *Arachis hypogaea*

MORPHOLOGICAL AND MOLECULAR CHARACTERIZATION OF ROOT-KNOT NEMATODE, *Meloidogyne enterolobii* INFECTING GUAVA (*Psidium guajava* L.)

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ABSTRACT

Root-knot nematode (*Meloidogyne enterolobii*) has emerged as a serious threat to guava (*Psidium guajava* L.) cultivation in several tropical regions. The present study aimed to characterize the nematode populations associated with guava wilt–nematode disease complex through detailed morphological, morphometric and molecular approaches. Infected root samples exhibiting typical galling symptoms were collected from major guava-growing districts of Tamil Nadu. The adult females were dissected from roots and examined for perineal pattern configuration, morphological and morphometric indices. The perineal pattern was oval to high dorsal arch without lateral lines, typical of *M. enterolobii*. Second-stage juveniles (J2) possessed a distinct hemispherical head, slender tail with a rounded terminus and a stylet length of 14.5–16.2 µm. Molecular identification using species-specific primers and amplification of the ITS and COI regions confirmed the identity of *M. enterolobii*. Phylogenetic analysis clustered the isolates with reference *M. enterolobii* sequences available in GenBank. The integrative characterization confirms the presence and distribution of *M. enterolobii* in guava orchards of Tamil Nadu and provides a reliable diagnostic basis for subsequent epidemiological and management studies.

Keywords: *Meloidogyne enterolobii*, guava, morphological characterization, molecular identification, COI, ITS

AGROECOLOGICAL INNOVATIONS FOR A PESTICIDE-FREE FUTURE

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ABSTRACT

Modern agriculture faces the tough task of producing high crop yields while protecting the environment. Heavy use of chemical pesticides has led to problems like upset ecosystems, pesticide-resistant pests, polluted soils and loss of helpful insects. Agroecological innovations offer a smarter, eco-friendly alternative by working with nature's own pest control methods. These sustainable strategies use natural enemies like predators, parasitoids and beneficial microbes, along with plant-based pesticides made from neem, pongamia and garlic. They also include smart farming practices such as planting flower strips, trap crops, hedgerows and diversifying crops to naturally reduce pests, boost biodiversity and improve soil health. New technologies have made these green methods even more effective. For example, nano biopesticides allow precise and slow release of pest control agents. RNA interference (RNAi) targets specific genes in pests without harming other species. Digital tools like AI pest monitoring help farmers take quick and accurate action, tailored to each field's needs. In India, these approaches have shown great success. In Tamil Nadu, flower strips in rice fields attract natural pest enemies and reduce pest damage. Cotton farms in Maharashtra use tiny parasitic wasps along with neem-based sprays to cut down bollworm damage and raise yields. Maize farms using push-pull systems manage stem borer pests while improving crop health. These ecological innovations mark a major shift away from chemical dependency toward farming systems that can regulate themselves. By blending natural processes with modern tools, they offer sustainable ways to protect crops, keep the environment safe and support food security for the future.

Keywords: Agroecology, Sustainable pest management, Biological control, Botanical pesticides, Nano biopesticides, RNA interference, Integrated crop protection

INNOVATIVE ECO-EVOLUTIONARY APPROACHES FOR SUSTAINABLE INTEGRATED PEST MANAGEMENT IN HORTICULTURAL ECOSYSTEMS

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ABSTRACT

Sustainable pest management demands approaches that integrate ecological principles with evolutionary insights to minimize pest resurgence and resistance development. The present study evaluates eco-evolutionary dynamics in major sucking pest complexes of horticultural crops, with a focus on whiteflies and their associated parasitoids and predators. Field trials combined with laboratory assays were conducted to understand temporal shifts in pest populations, natural enemy adaptation, and the influence of microclimatic factors on trophic interactions. Novel strategies such as habitat manipulation, banker plant systems, and selective biopesticide schedules were tested to enhance biological control efficiency. Findings revealed that diversified cropping systems improved parasitoid stability and reduced whitefly incidence by 42–58% compared to conventional practices. Biopesticide rotation based on resistance-breaking modes of action also significantly delayed resistance development in key pest species. This work illustrates the potential of integrating eco-evolutionary concepts with practical IPM components to deliver resilient, adaptable, and cost-effective pest management solutions for horticultural growers.

Keywords: Innovative, Eco-Evolutionary Approaches, Sustainable pest management Integrated Pest Management, Horticultural Ecosystems

ADVANCEMENTS IN BIOLOGICAL CONTROL AND DIGITAL DECISION-SUPPORT TOOLS FOR NEXT-GENERATION IPM PROGRAMS

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ABSTRACT

Biological control, when combined with precision-based decision-support tools, has emerged as a cornerstone of modern IPM programs. The present work explores innovations in mass production techniques for key biocontrol agents, including Trichogramma chilonis, Chrysoperla zastrowii sillemi, and entomopathogenic fungi such as Beauveria bassiana and Metarhizium anisopliae. Concurrently, a digital pest advisory tool integrating real-time weather data, pest phenology models, and spatial pest surveillance was developed to support timely IPM interventions. Validation across vegetable and field crop ecosystems demonstrated that the integration of biological control with digital advisories reduced insecticide use by 35–48% while maintaining yield stability. Enhanced release timing based on degree-day models improved Trichogramma parasitism efficiency by 22%. This study highlights the synergy between biocontrol innovation and digital agriculture, offering a robust framework for next-generation IPM tailored for climate-smart and resource-efficient farming.

Keywords: Advancements, Biological Control, Digital Decision-Support Tools, IPM Programs

PATHOGEN-HOST DYNAMICS AND MANAGEMENT APPROACHES FOR LITTLE LEAF OF BRINJAL

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ABSTRACT

Little leaf disease of brinjal (*Solanum melongena* L.) is a severe phytoplasma-associated disorder that significantly reduces yield and quality. The disease is primarily transmitted by phloem-feeding leafhoppers, notably *Hishimonus phycitis*, which play a key role in pathogen spread under favorable environmental conditions. Infected plants show symptoms including drastic reduction in leaf size, shortened petioles and internodes, proliferation of axillary shoots, chlorosis, phyllody, stunted growth, and poor or absent fruit set. Severe outbreaks can result in yield losses up to 90%. An integrated strategy that incorporates vector control, the use of resistant germplasm, cultural and hygienic measures, and sound agronomic techniques is necessary for effective management. The pathogen-host dynamics, epidemiology, symptomatology, and integrated management approaches for small leaf of brinjal are reviewed in this chapter, with a focus on current developments in phytoplasma detection, vector control, and the creation of resistant varieties.

Key words: Little leaf disease, *Solanum melongena,* Phytoplasma, IDM, Brinjal, Epidemiology, *Hishimonus phycitis*

Introduction

Brinjal, commonly known as eggplant, is an important solanaceous vegetable widely cultivated in tropical and subtropical regions, supporting the livelihoods of many small and marginal farmers. Among its major diseases, little leaf poses one of the most serious threats, often resulting in complete loss of yield. The causal agent is a wall-less bacterial pathogen, belonging to the phytoplasma group (previously called mycoplasma-like organisms), which colonizes the phloem and is transmitted by leafhoppers, primarily *Hishimonus phycitis*. (Lee *et al.,* 2000; Kumar & Ram, 2021) Infected plants exhibit reduced leaf expansion, shortened internodes, chlorosis, leaf malformations, proliferation of axillary shoots, phyllody, and poor or absent fruiting. Sometimes fruits stay tiny and unmarketable. The number of vectors, climatic factors like humidity and temperature, and the existence of substitute hosts like volunteer plants and solanaceous weeds all affect the spread of disease. According to recent molecular research, brinjal can be infected by several phytoplasma ribosomal groups, including 16SrI, 16SrII, 16SrIII, 16SrV, 16SrVI, and 16SrXII. Furthermore, research conducted in insect-proof greenhouses suggests that seed transmission from symptomatic plants to seedlings is feasible, however it seems to be a small source of inoculum. Variability in susceptibility has been found by screening of brinjal germplasm; certain accessions consistently exhibit resistance in various situations. (Amin *et al.,* 2019) The environmental dependence of vector dynamics is reflected in epidemiological studies, which show that disease incidence is highest during Zaid (March–June), followed by Kharif and Rabi seasons.

Symptoms and Disease Diagnosis

Brinjal little leaf disease causes noticeable morphological anomalies that start with the leaves. Because of chlorosis, the leaves get very tiny, turn pale yellow to light green, and have uneven margins and a leathery texture. Internodes shorten dramatically as the disease worsens, resulting in stunted growth and a dense, bushy appearance from excessive lateral branch multiplication. Additionally impacted are the reproductive organs; flowers are frequently infertile, tiny, and deformed. When they form, the few, tiny, hard, and malformed fruits cause a significant decrease in yield. (Amin *et al.,* 2019).

Although field symptoms provide a trustworthy initial identification, a precise diagnosis of tiny leaf disease requires laboratory confirmation. Phytoplasma bodies in phloem tissues can be found using microscopic techniques like DAPI staining, but molecular approaches like PCR, nested PCR, real-time PCR, LAMP, and ELISA offer accurate and quick identification even before symptoms manifest. In order to ensure that therapy options are founded on accurate identification of the causal agent, differential diagnosis is crucial in differentiating tiny leaf from illnesses with similar symptoms, such as zinc deficiency, viral mosaic infections, and herbicide harm.

Phytoplasma Classification and Biology:

Due to their incapacity to grow on artificial media, phytoplasmas, which are wall-less, phloem-restricted prokaryotes that belong to the class Mollicutes, order Acholeplasmatales, and family

Acholeplasmataceae, are taxonomically grouped based on 16S rRNA gene sequence similarity rather than traditional culture-based classification. They only live in the hemolymph of insect vectors and the phloem tissues of host plants. They have pleomorphic, filamentous bodies without a cell wall. The phytoplasma linked to brinjal little leaf disease is typically categorized within the 16SrVI category (Ghosh & Mukherjee, 2018). It is distinguished by systemic colonization of phloem elements, where it interferes with growth regulation, nutrient transport, and plant hormone balance. Phytoplasmas are biologically complicated and epidemiologically aggressive since they are totally dependent on living hosts for survival and can proliferate both in plant phloem and within insect vectors. Their ability to cause severe morphological problems in plants, including small leaf symptoms, is attributed to their unusual biology, which includes obligate parasitism, persistent propagative transmission by leafhoppers, and tremendous genetic variety. (Ahmad & Khan, 2020)

Mechanism of Pathogen Transmission

Only leafhopper vectors can spread little leaf disease in brinjal; *Hishimonus phycitis* is known to be the most effective and common species that spreads phytoplasma, though other leafhoppers like *Halticus spp.* as well as Cicadulina species. may contribute in localized regions (Sundar & Karthikeyan, 2017). These vectors acquire the phytoplasma while feeding on phloem sap of infected plants and subsequently transmit it to healthy hosts during later feeding cycles. The mode of pathogen transmission is persistent and propagative, meaning the phytoplasma lives, multiplies, and circulates within the vector's body after ingestion, including passage via the midgut, hemolymph, and lastly into the salivary glands. (Nikhil & Singh, 2023) The vector becomes infectious for life and spreads the infection to all susceptible plants it feeds on after a latent period necessary for pathogen proliferation and movement within the insect. Under ideal environmental conditions, disease spreads very quickly due to the close biological relationship between phytoplasma and leafhoppers, as well as the high mobility and quick reproduction of vectors. This emphasizes the significance of vector surveillance in disease prediction and management.

Pathogen–Host Dynamics and Epidemiology

Stunted growth and decreased leaf expansion are symptoms of phytoplasmas, which live in the phloem and hinder nutrition transfer. Leafhoppers facilitate the rapid spread of illness by acquiring the phytoplasma from sick plants and inoculating healthy plants during successive feedings.

Although less important in the field, seed transfer has been documented in controlled environments. Different brinjal accessions have different host susceptibilities, which emphasizes the significance of resistant germplasm in disease control. Temperature, humidity, and rainfall are examples of environmental conditions that have a big impact on vector populations and the spread of illness. These dynamics show that rather than depending on a single strategy, successful little leaf disease control necessitates an integrated approach that targets the pathogen, the vector, and host vulnerability. (Amin *et al.,* 2019)

The pathogen–host–vector dynamics is key to designing effective management strategies. Important aspects include:

Chemical techniques can be combined with biological control of vectors and natural predators to reduce the impact on the ecosystem. Tetracycline and other antibiotic sprays have long been used to fight phytoplasmas, but their field use is limited due to environmental and legal concerns. Regular field monitoring, early detection by molecular diagnostics, and farm hygiene practices are essential to preventing the spread of disease and maintaining sustainable output.

Vector Population Dynamics and Seasonal Trends: The population dynamics of leafhopper vectors, particularly *Hishimonus phycitis*, play a central role in the spread of little leaf disease in brinjal. Leafhopper populations fluctuate seasonally, with peak densities typically occurring during the Zaid season (March–June) in India, followed by lower populations during Kharif and Rabi seasons. These fluctuations are influenced by the availability of host plants, breeding habitats, and natural enemies. Higher vector populations during favorable periods increase the rate of phytoplasma transmission, leading to greater disease incidence and severity in susceptible brinjal crops. Understanding the seasonal trends of vector populations is crucial for predicting outbreaks and implementing timely control measures. (Ahmad & Khan, 2020; Nikhil & Singh, 2023).

Environmental Influence on Disease Spread: Environmental factors such as temperature, humidity, rainfall, and the presence of alternate host plants significantly affect the spread of little leaf disease. Warm and humid conditions favor rapid leafhopper development and feeding activity, enhancing pathogen transmission, whereas extreme temperatures or heavy rainfall may suppress vector activity and slow disease spread. The presence of weeds or volunteer solanaceous plants provides additional reservoirs for both the phytoplasma and its vectors, exacerbating disease incidence under conducive environmental conditions. Consequently, integrating knowledge of environmental influences with vector monitoring is essential for designing effective disease management strategies and minimizing crop losses.

Seed and Alternate Host Considerations: Although leafhopper vectors are the main way that phytoplasma is spread, there is evidence that contaminated seed stock may contribute to the emergence of illness in controlled settings, which raises concerns regarding seedborne inoculum. Furthermore, a variety of weed species and solanaceous volunteers act as asymptomatic reservoirs for the disease and its vectors, facilitating long-term seasonal survival and aiding in the accumulation of early-season inoculum in brinjal fields. Weed control and seed health evaluation are essential elements of disease prevention because the survival of alternative hosts close to agricultural regions speeds up vector movement and disease start. Therefore, it is crucial to monitor reservoir hosts, strengthen seed certification processes, and sanitize field borders in order to minimize primary infection sources.

Host Susceptibility and Germplasm Variability: The prevalence and severity of little leaf disease vary significantly throughout agro-ecological zones due to variations in host susceptibility. Anatomical, biochemical, or molecular characteristics that prevent pathogen colonization or lessen vector attractiveness may be linked to the different levels of tolerance or resistance to phytoplasma infection displayed by some brinjal genotypes. Even while commercial cultivars with high yields are readily available, many of them are still very prone to infection, which accelerates the spread of the disease in endemic areas. Therefore, identifying and incorporating resistant genetic sources into breeding programs continues to be a priority for sustainable brinjal production, and screening germplasm and breeding for resistance are essential components of long-term disease management.

Integrated Management Approaches

Cultural, hygienic, host resistance, and vector control methods are all combined in integrated management (IPM) initiatives. Crop rotation with non-host crops to break the disease cycle, field sanitation by removing crop debris and alternate hosts, and roguing and destroying sick plants to limit inoculum are examples of cultural and sanitary techniques. Using tolerant or resistant brinjal accessions to create host resistance is a promising long-term approach. Accessions with lower susceptibility have been found through screening and ought to be included in breeding initiatives. Leafhopper populations can be decreased by carefully applying systemic or contact insecticides, such as organophosphates and neonicotinoids. Vector management is crucial. To lessen the impact on the ecosystem, chemical methods can be used with biological control of vectors and natural predators. Despite the fact that antibiotic sprays like tetracycline have long been used to combat phytoplasmas, their field application is restricted because of environmental and regulatory issues. To stop the spread of disease and preserve sustainable production, routine field monitoring, early detection by molecular diagnostics, and farm cleanliness procedures are crucial. (Ghosh & Mukherjee, 2018).

The first line of defense consists of cultural and hygienic techniques, such as field sanitation, crop debris clearance, roguing—the killing of sick plants—and crop rotation with non-host crops to lower inoculum and vector reservoirs. These steps aid in preserving field cleanliness and preventing the spread of illness.

Using tolerant or resistant brinjal varieties greatly lowers the incidence of disease; screening and breeding programs centered on resistant germplasm are crucial to creating cultivars appropriate for various agroclimatic zones. This is a sustainable long-term strategy. Since leafhoppers are the main carriers of phytoplasma, vector management is essential. While biological control, which uses natural predators and parasitoids, offers an environmentally safe substitute, chemical control, which involves the prudent use of systemic or contact pesticides, can lower vector populations. By incorporating these techniques into an IPM (Integrated Pest Management) framework, the use of insecticides is reduced and effective vector suppression is ensured.

Cultural and Sanitary Practices

The primary and most important method for controlling brinjal tiny leaf disease is cultural and hygienic practices. In order to eradicate alternate hosts that carry phytoplasma and leafhopper vectors, these methods place a strong emphasis on the use of certified and disease-free planting material, prompt removal and destruction of sick plants, and stringent weed control. Reducing vector landing and pathogen survival can be achieved through crop rotation with non-host crops, adhering to approved plant spacing, managing nutrients in a balanced manner, and maintaining good field hygiene. These straightforward but efficient agronomic methods greatly reduce primary inoculum levels and aid in the long-term suppression of disease. (Lee *et al.,* 2000)

Host Resistance

By reducing infection without using large amounts of insecticides, host resistance offers a cost-effective and environmentally responsible method of managing illness. Different brinjal germplasm has been screened in both controlled and field settings to find resistant or tolerant cultivars with less severe symptoms and less phytoplasma buildup. The production of better varieties is still being advanced by breeding efforts that emphasize the inclusion of resistance characteristics and molecular marker-assisted selection. Using resistant cultivars lowers input costs and environmental hazards while significantly increasing yield stability.

Vector Control (Chemical, Biological, and IPM)

Since leafhopper vectors are the only means of phytoplasma transmission, vector control is still an essential part of the disease management approach. When used at acceptable intervals based on pest monitoring, chemical treatment with selective insecticides can successfully lower vector populations and the spread of illness. (Kumar & Ram, 2021). In an IPM strategy, biological interventions such as the use of parasitoids, predators, entomopathogenic fungi, and plant-based biopesticides offer safer alternatives for the environment and can be combined with chemical control. Further reducing vector accumulation and promoting natural enemy activity are ecological strategies include reflective mulching, trap farming, yellow sticky traps, neem-based treatments, and habitat modification.

Molecular and Diagnostic Approaches

By making it possible to quickly and accurately identify the phytoplasma pathogen, recent developments in molecular diagnostics provide strong support for integrated control initiatives. Loop-mediated isothermal amplification (LAMP), PCR, nested PCR, real-time PCR, DNA barcoding, and other techniques enable early infection confirmation prior to the onset of symptoms, allowing for prompt action. In order to test breeding materials for disease resistance and expedite the production of resistant varieties, molecular markers are being utilized more and more. Additionally, molecular surveillance of pathogen and vector populations strengthens the use of focused and prompt control measures by supporting epidemiological forecasting and decision-support systems (Sundar & Karthikeyan, 2017).

Conclusion

Little leaf disease of brinjal is a complicated and destructive condition that causes significant yield losses and low-quality fruits. It is mostly spread by leafhopper vectors and is brought on by phytoplasma infection. The disease is difficult to manage because of a variety of characteristics, such as host vulnerability, vector population dynamics, seasonal trends, and environmental circumstances. (Manjunatha & Rai, 2022)An integrated strategy that incorporates cultural and hygienic practices, the use of resistant cultivars, chemical and biological vector management, and molecular diagnostic technologies for early identification is necessary for effective control. To reduce disease incidence, farmer awareness, prompt interventions, and adherence to suggested management techniques are crucial. Sustainable production will be further improved by ongoing research on resistant germplasm, environmentally friendly vector control, molecular diagnostics, and climate-resilient management. In areas impacted by little leaf disease, putting such integrated measures into practice guarantees the stabilization of brinjal yield, lowers financial losses, and encourages sustainable agriculture.

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INTEGRATION OF DIGITAL DECISION-SUPPORT TOOLS AND BIOLOGICAL CONTROL: A CONTEMPORARY REVIEW FOR CLIMATE-SMART INTEGRATED PEST MANAGEMENT IN VEGETABLE ECOSYSTEMS

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Abstract

Climate variability has intensified insect pest problems in vegetable cropping systems, reducing the efficacy of conventional Integrated Pest Management (IPM). Digital decision-support tools—such as mobile apps, weather-based forecasting, geospatial surveillance, and IoT-based automated traps—offer timely pest predictions and advisory services. Concurrently, advancements in biological control, including mass production technologies and climate-adaptive natural enemies, provide sustainable, eco-friendly pest suppression. This review synthesizes global research on integrating digital agricultural tools with biological control for climate-smart IPM. Evidence shows that such integration can reduce pesticide applications by 35–55%, enhance parasitism and predation rates by up to 30%, and improve crop productivity under climate stress. Research gaps, barriers to adoption, and future opportunities are discussed.

1. Introduction

Vegetable ecosystems in tropical and subtropical regions encounter frequent pest outbreaks due to rapid insect reproduction, favourable microclimates, and increased host availability. Climate anomalies—temperature spikes, unseasonal rains, and prolonged humidity—exacerbate pest infestations and disrupt natural enemy populations. Traditional pest management largely depends on broad-spectrum insecticides, leading to resistance, residue concerns, biodiversity loss, and human health risks.

The rise of digital agriculture tools enables real-time pest diagnosis, forecasting, and decision-making. When such tools are integrated with biological control agents—parasitoids, predators, and entomopathogenic fungi—they strengthen IPM and increase ecological resilience.

This review examines recent advances, integration strategies, field outcomes, and future perspectives of combining digital advisory tools with biological control for climate-smart IPM in vegetable crops.

2. Biological Control in Modern IPM

2.1 Overview of Biological Control

Biological control involves suppressing pest populations using natural enemies. In vegetable ecosystems, widely used bioagents include:

- *Trichogramma chilonis* – egg parasitoid for lepidopteran borers
- *Chrysoperla zastrowii sillemi* – predator of aphids, whiteflies, thrips
- *Coccinellidae* spp. – predators of soft-bodied insects
- *Beauveria bassiana*, *Metarhizium anisopliae* – entomopathogenic fungi

2.2 Climate Sensitivity of Biological Control Agents

- Parasitoids exhibit faster development at moderate temperatures but reduced parasitism under extreme heat.
- Predators like *Chrysoperla* maintain high predation rates across varied temperatures, making them robust under climate stress.
- Fungal pathogens require high humidity; their efficacy decreases when RH falls below 70%.

Hence, **accurate timing** of releases and applications is crucial—an area where digital tools contribute significantly.

3. Digital Decision-Support Tools for Pest Management

3.1 Weather-Based Pest Forecasting Models

Degree-day models, humidity thresholds, and rainfall correlations are used to predict outbreaks of key pests such as *Helicoverpa armigera*, whiteflies, and aphids.

3.2 Mobile-Based Advisory Systems

Apps like Plantix, mKRISHI, and state university advisory systems offer WhatsApp-based pest diagnosis, photo identification, and IPM advisories.

3.3 GIS and Remote Sensing

Geospatial mapping helps identify pest hotspots, track spread patterns, and guide targeted biological control releases.

3.4 IoT-Based Smart Traps and Sensors

Smart pheromone traps, automated sticky traps, and weather sensors enable real-time pest surveillance and trigger automated advisories.

4. Integrating Digital Tools with Biological Control

4.1 Improved Timing of Releases

Digital forecasts help determine the correct release window for *Trichogramma*, optimal larval stage for *Chrysoperla*, and humidity-based timing for fungal sprays.

Field studies show:

- 18–30% increase in parasitism under digital scheduling
- Higher predator establishment and survival
- Efficient use of fungal pathogens during favourable humidity periods

4.2 Reduction in Pesticide Use

Integrated systems reduce chemical sprays by **35–55%**, conserving beneficial arthropods and reducing production costs.

4.3 Enhanced Economic Returns

Lower pesticide inputs, reduced crop loss, and better natural enemy performance contribute to improved benefit–cost ratios.

4.4 Case Studies

Case Study 1: Tomato Fruit Borer Management

Degree-day based *Trichogramma* releases increased parasitism by 22% and reduced damage by 38%.

Case Study 2: Chrysoperla in Cucurbits

GIS mapping guided spot releases, improving predation by 25%.

Case Study 3: Fungal Biopesticides

Auto-sensing humidity modules allowed precise fungal application, enhancing efficacy by 30%.

5. Challenges and Barriers to Adoption

- **Digital literacy gaps** among smallholder farmers
- **Connectivity issues** in remote villages
- **Region-specific model customization** required
- **High production cost** of quality biocontrol agents
- **Limited integration** of biological control modules in digital apps

6. Future Directions

6.1 AI-Driven Pest Prediction

Machine learning models can improve forecast accuracy.

6.2 Unified Digital Platforms

Integration of image-based pest detection, weather forecasts, soil sensors, and biocontrol advisory modules.

6.3 Climate-Adaptive Biological Control Agents

Development of heat-tolerant parasitoid strains and resilient entomopathogenic fungi.

6.4 Regional Language Apps & Chatbot Systems

Voice-assisted recommendations will improve farmer adoption.

6.5 Policy Support

Schemes supporting digital farming infrastructure and subsidized biocontrol agents.

7. Conclusion

Combining digital decision-support tools with biological control offers a robust pathway to climate-smart IPM in vegetable ecosystems. Digital tools enhance the precision of natural enemy releases, reduce pesticide use, and improve ecological sustainability. Broader adoption requires farmer training, infrastructural support, and continuous research to refine predictive models and adapt natural enemies to climate variability.

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DIGITAL FRONTIERS IN IPM: PRECISION MANAGEMENT OF SHOOT AND FRUIT BORER (*Leucinodes orbonalis*) IN BRINJAL

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ABSTRACT

The brinjal shoot and fruit borer (*Leucinodes orbonalis*) is a key production constraint in solanaceous systems, inflicting yield losses of up to 60–70 per cent by boring into shoots and fruits, thereby reducing both marketable yield and quality. Conventional reliance on repeated insecticide applications has proven unsustainable due to the pest's cryptic feeding behaviour, resistance build-up, and adverse ecological and food safety implications. Precision-driven Integrated Pest Management (IPM) approaches hold transformative potential in this context. Digital surveillance tools, including sensor-enabled pheromone traps and image-based pest recognition systems, enable real-time monitoring of pest dynamics with spatial accuracy. Decision-support platforms, powered by predictive analytics and weather-linked forewarning models, facilitate timely interventions and optimize input use. Drone-based deployment of biopesticides and natural enemies enhances field-scale efficacy while reducing labour intensity. Coupled with ecological tactics such as release of egg parasitoids (*Trichogramma chilonis*), use of neem-based formulations, and destruction of infested plant parts, these digital frontiers create a synergistic and environmentally sound pest management framework. Mobile-based advisories and farmer-centric digital platforms further bridge knowledge gaps, ensuring adoption of climate-resilient and sustainable strategies. Harnessing technological innovations alongside ecological principles can redefine brinjal protection systems, delivering precision, profitability, and sustainability to smallholder farmers.

Keywords: *Leucinodes orbonalis*, Brinjal, Precision IPM, Digital surveillance, Biological control and Climate-smart pest management.

TECHNOLOGY-DRIVEN PEST MANAGEMENT IN HORTICULTURAL CROPS

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ABSTRACT

Traditional pest management methods often rely on broad-spectrum chemical applications, which can lead to environmental concerns, pest resistance, and non-target species impact. In contrast, digital innovations enable more targeted, efficient, and sustainable approaches. Remote sensing technologies, such as drones equipped with multispectral and thermal imaging, allow for real-time monitoring of crop health and pest infestations over large areas. These tools help identify problem zones precisely, reducing unnecessary pesticide use. Additionally, the integration of Geographic Information Systems (GIS) and Geographic Positioning Systems (GPS) facilitates spatial analysis and mapping of pest populations, enabling farmers to make informed decisions tailored to specific field conditions. Furthermore, advancements in machine learning and data analytics enable predictive modelling of pest outbreaks based on weather patterns, crop phenology, and historical data, allowing for timely interventions. Mobile apps and digital platforms provide farmers with accessible pest identification guides, treatment recommendations, and communication channels with experts, enhancing decision-making at the farm level. Precision application technologies, such as variable rate sprayers, ensure that pesticides are applied only where needed and in optimal amounts, reducing chemical usage and environmental impact. Overall, digital innovations in IPM are making pest control more sustainable, cost-effective, and environmentally friendly, ultimately leading to healthier crops, higher yields, and safer food production in horticulture.

Keywords: Pests management, Horticultural Crops, Remote sensing, GIS

NANO-BIOPESTICIDE AND ENTOMOPATHOGENIC FUNGI SYNERGY FOR SUSTAINABLE MANAGEMENT OF MULBERRY PINK MEALY BUG (*Maconellicoccus hirsutus*)

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ABSTRACT

The pink mealy bug (*Maconellicoccus hirsutus* Green) is one of the most destructive pests of mulberry, causing significant reductions in leaf yield and silkworm cocoon productivity. The present study evaluates the synergistic potential of nano-biopesticides formulated from botanicals (neem, pongamia, citronella) in combination with entomopathogenic fungi (*Beauveria bassiana* and *Lecanicillium lecanii*). Experiments conducted from 2022 to 2025 involved laboratory bioassays, pot-culture trials, and field-level evaluations. Nano-bioformulations exhibited enhanced penetration, improved stability, and higher pest mortality compared to conventional formulations. The combined nano-neem oil + *L. lecanii* treatment produced the highest corrected mortality (92.4%), greatest nymphal suppression (88%), and maximum reduction in oviposition. Field trials demonstrated 38–45% improvement in leaf yield over untreated controls. SEM studies confirmed rapid cuticular disruption, while biochemical analyses showed reduced trehalase and esterases in treated mealy bugs. The results confirm that nano-biopesticides integrated with fungal pathogens offer a sustainable, residue-safe, and climate-resilient strategy for mulberry pest management.

Introduction

Mulberry (*Morus indica*) serves as the primary food plant for the silkworm *Bombyx mori*, and pest infestation on mulberry directly affects cocoon yield, fibre strength, and the economic viability of sericulture. Among various pests, the pink mealy bug (*Maconellicoccus hirsutus*) has emerged as a major threat due to its polyphagous nature, rapid reproduction, protective wax covering, and resistance to chemical insecticides. Its feeding causes leaf yellowing, curling, shoot malformation, and heavy honeydew secretion, favouring sooty mould, ultimately reducing leaf quality for silkworm rearing.

Increasing global emphasis on pesticide-free sericulture demands eco-friendly and residue-safe technologies. Entomopathogenic fungi (EPF) such as *Beauveria bassiana* and *Lecanicillium lecanii* are well known for their ability to infect sucking pests. However, their field efficacy is often limited by environmental conditions and slow penetration into protective wax layers.

Nanotechnology-based biopesticides (nano-bioformulations) improve solubility, adhesion, bioavailability, and stability of botanical oils, enabling better action against pest cuticles. The concept of combining nanoparticles with EPF—synergistic "nano–bio synergy"—is emerging as a frontier technology in sustainable pest management. This study aims to develop, test, and validate nano-biopesticide + EPF combinations for effective suppression of *M. hirsutus* under laboratory and field conditions.

Materials and Methods

The study was conducted from January 2022 to March 2025 at the Department of Entomology & Sericulture, SRM College of Agricultural Sciences, Baburayenpettai, Chengalpattu District, Tamil Nadu (12.67°N, 79.96°E; elevation 60–75 m). The region experiences a tropical climate with mean temperatures of 27–35°C and 65–85% relative humidity, conditions conducive to pink mealy bug (*Maconellicoccus hirsutus*) outbreaks. Field validation trials were carried out in farmer fields in Thirukazhukundram, Mamandur, and Chengalpattu.

Collection and Maintenance of Pink Mealy Bug Culture

Infested mulberry twigs (varieties MR2 and V1) were collected from local sericulture farms and brought to the laboratory. Adult females and nymphs were transferred to clean, potted mulberry plants maintained in insect-proof culture chambers (26 ± 2°C, 75 ± 5% RH, 14L:10D). Fresh colonies were refreshed every 30 days to ensure uniform age structure. Nymphs of 2–3 days old and gravid adult females were used for uniform bioassays.

Preparation of Botanical extracts -Nano-Biopesticide Formulations

Botanical raw materials were collected from authenticated sources:

- Neem seed kernel extract (NSKE, cold-pressed)
- Pongamia oil (Karanja)
- Citronella oil (Cymbopogon winterianus)

Filtered extracts were stored at 4°C until nano-formulation.

Nanoemulsion synthesis

Nanoemulsions were prepared by a two-step high-energy ultrasonication method:

1. Primary emulsion formation:
    - Oil phase mixed with Tween-80 (10–12% w/v).
    - Distilled water added dropwise while stirring at 10,000 rpm.
2. Nano-sizing:
    - Mixture ultrasonicated at 20 kHz, 750 W for 10 minutes.

Physical and chemical characterisation

- Dynamic Light Scattering (DLS): droplet size (60–120 nm) and PDI (<0.25).
- Zeta potential: stability indicator (> −30 mV).
- Transmission Electron Microscopy (TEM): spherical, uniform droplets.
- FTIR analysis: to confirm structural stability of bioactive compounds.

All nanoemulsions were diluted to 0.5% for experiments.

Entomopathogenic Fungi (EPF)

Strain selection

Two locally adapted fungal isolates were used:

- *Beauveria bassiana* (strain BB-SRM01)
- *Lecanicillium lecanii* (strain LL-SRM02)

Conidial preparation

Fungi were cultured on PDA plates for 14 days at 25°C. Conidia were harvested and suspended in 0.01% Tween-80 solution, then adjusted to 1×10^8 conidia/mL using a haemocytometer.

Conidial viability

Viability (> 95% germination) confirmed by plating on agar and incubating for 24 hours.

Treatment Combinations

Nine treatments were prepared for laboratory and field evaluation:

Code	Treatment	Concentration
T1	Control (water)	–
T2	Conventional neem oil	2%

Code	Treatment	Concentration
T3	Nano-neem	0.5%
T4	Nano-pongamia	0.5%
T5	Nano-citronella	0.5%
T6	*B. bassiana*	1×10^8 conidia/mL
T7	*L. lecanii*	1×10^8 conidia/mL
T8	Nano-neem + *L. lecanii*	0.5% + 1×10^8
T9	Nano-pongamia + *B. bassiana*	0.5% + 1×10^8

Mixtures were prepared fresh before each experiment.

Laboratory Bioassay Procedures and Leaf-disc spray bioassay

- Mulberry leaves washed and cut into 5 cm discs.
- Mealy bugs (20–25 nymphs/leaf) were allowed to settle for 12 hours.
- Treatments applied using a Potter spray tower (1 mL/disc, 1.5 kg/cm² pressure).
- Mortality observed at 24, 48, 72, and 96 hours.

Assessment parameters

- Mortality (%) corrected using Abbott's formula.
- Nymphal development inhibition index (NDI).
- Adult fecundity (eggs/female).
- Ovisac production.
- Behavioural changes (mobility, clustering, wax exudation).

Pot-Culture Trials

Twenty-day-old mulberry saplings were inoculated with 50 nymphs per plant. After 5 days, treatments were applied with a hand sprayer (30 mL/plant). Pest population was monitored at 7, 14, and 21 days after treatment (DAT). Leaf chlorophyll content measured using SPAD-502 meter to assess plant recovery.

Field Experiments and design

- Randomized Block Design (RBD)
- 3 replications

- 50 plants per treatment
- Spacing: 60 × 60 cm

Field observations

- Mealy bug population per leaf (10 leaves/plant).
- Honeydew severity index (1–5 scale).
- Sooty mould coverage (%).
- Leaf yield per plant (g/plant/cycle).
- Silkworm feeding acceptance (leaf palatability).

Safety evaluation

Leaf residue analysis performed using HPLC to ensure no harmful residues for silkworm feeding.

Scanning Electron Microscopy (SEM)

Adult mealy bugs treated with selected formulations (T3, T8, T9) were fixed in 2.5% glutaraldehyde, dehydrated with ethanol series, dried, gold-coated, and examined under SEM (JEOL JSM-IT200). Parameters observed:

- Wax layer integrity
- Cuticle cracking
- EPF hyphal penetration
- Conidial adhesion and germination

Biochemical Enzyme Assays

Enzymatic profiles were evaluated from treated and untreated mealy bugs.

Trehalase activity:

Measured using the glucose standard method (Somogyi–Nelson protocol).

Esterase activity: Determined using α-naphthyl acetate assay.

Total protein: Quantified using Bradford method.

Enzyme inhibition (%) calculated for comparisons.

Statistical Analysis

Data were subjected to:

- One-way ANOVA
- Tukey's HSD test at $p \leq 0.05$
- Abbott's correction for mortality
- Probit analysis for LC_{50} and LT_{50} estimation

Software used: SPSS v25 and R (agricolae package).

Results and Discussion

Nano-biopesticides demonstrated significantly higher efficacy than conventional botanical formulations. Nano-neem and nano-citronella caused rapid desiccation of the wax layer, enhancing EPF penetration. The highest corrected mortality (92.4%) was recorded in nano-neem + *L. lecanii* treatment (T8), followed by nano-pongamia + *B. bassiana* (T9) with 88.7% mortality. Conventional neem oil showed only 53% mortality.

Nymphal development was severely inhibited in T8 and T9, with >80% reduction in adult female fecundity. SEM images confirmed structural disintegration of the wax coating, which facilitated fungal hyphae entry. Biochemical assays revealed a 42–55% reduction in trehalase and esterase levels, indicating metabolic failure in the pest.

Field trials corroborated laboratory findings: T8 treatment achieved 78% population reduction, lowered honeydew deposition significantly, and improved mulberry leaf yield by 41.2% over control. Silkworm acceptance tests showed no negative residues, confirming safety for sericulture systems.

The observed synergy arises from the nanoemulsion's ability to break the hydrophobic barrier, thus promoting fungal infection—a phenomenon increasingly recognized in advanced IPM research. These results establish nano–bio synergy as a transformative approach in mulberry pest management.

Conclusion

The present study demonstrates that nano-biopesticides combined with entomopathogenic fungi offer a highly effective, eco-friendly, and sustainable technology for managing the pink mealy bug (*Maconellicoccus hirsutus*) in mulberry ecosystems. The nano-neem + *L. lecanii* combination emerged as the most potent treatment, delivering superior mortality, reduced reproduction, and improved plant recovery. The synergy between nanoemulsions and EPF enhances pest cuticle disruption, accelerates fungal infection, and ensures high field efficacy under tropical conditions. Integration of these nano–bio tools into sericulture-based IPM systems holds promise for pesticide-free leaf production, improved cocoon yield, and long-term sustainability.

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NEW MOLECULE SPIROTETRAMAT 150 OD (MOVENTO) AGAINST APHID, *Aphis gossypii* IN BRINJAL

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ABSTRACT

Brinjal (*Solanum melongena* L.) is an important vegetable crop widely cultivated in tropical and subtropical regions, but its productivity is severely affected by sucking pests, particularly the aphid *Aphis gossypii*. Aphid infestation leads to direct yield losses through sap extraction, honeydew secretion, and indirect losses through the transmission of viral diseases. Spirotetramat 150 OD, a novel tetramic acid insecticide with systemic and ambimobile properties, has emerged as an effective option for managing sucking insect pests. The present study evaluates the bioefficacy of spirotetramat 150 OD against *A. gossypii* in brinjal. Field applications of spirotetramat 150 OD at recommended doses resulted in a significant reduction in aphid population compared to untreated control plots. The insecticide exhibited prolonged control due to its unique mode of action targeting lipid biosynthesis, thereby affecting aphid development, fecundity, and population growth. Spirotetramat 150 OD demonstrated comparable or superior efficacy to standard chemical insecticides, with the added advantage of systemic protection of new plant growth. The results indicate that spirotetramat 150 OD is an effective and IPM-compatible molecule for sustainable management of brinjal aphid, offering a valuable tool for reducing crop losses while minimizing the risk of resistance development.

Key words: spirotetramat, brinjal, aphids, sucking pests and brinjal

1. Introduction

Brinjal (*Solanum melongena* L.) is a widely cultivated vegetable crop in tropical and subtropical regions, valued for its nutritional and economic importance. As it is cultivated round the year, a wide range of insect pests attacks the crop right from its seedling stage in the nursery to its harvesting in the main field (Ragupathy et al., 1997). The major insect pests of brinjal affecting the quantitative as well as qualitative yield are shoot and fruit borer (*Leucinodes orbonalis* Guenee), jassid (*Amrasca* sp.), white fly

(*Bemisia tabaci* Genn.), aphid (*Aphis gossypii* Glover) and red spider mite (*Tetranychus* spp.) (Chakraborti *et al*., 2011). In terms of significant amounts of yield loss, sucking pests also cause a considerable amount of damage to the brinjal crop after *L. orbonalis*. These sucking pests causing about 50-70% of loss in yield. Among these, *A. gossypii* causes significant yield losses by direct sap extraction, honeydew secretion, and transmission of viral diseases. Effective management of aphids is therefore crucial for sustainable brinjal production.

2. Aphid *Aphis gossypii*: Biology and Damage

Aphids are small, soft-bodied insects with long, slender mouth parts that they use to pierce stems, leaves, and other tender plant parts and suck out plant fluids. Almost every plant has one or more aphid species that occasionally feeds on it. Aphids may be green, yellow, brown, red, or black depending on the species and the plants they feed on. A few species appear waxy or woolly due to the secretion of a waxy white or gray substance over their body surface. All are small, pear-shaped insects with long legs and antennae. Most species have a pair of tube like structures called cornicles projecting backwards out of the hind end of their bodies. The presence of cornicles distinguishes aphids from all other insects. *Aphis gossypii* is a cosmopolitan pest with high reproductive potential. It favors warm temperatures and high humidity, establishing dense colonies on tender plant parts. The pest's feeding weakens the plant, causes leaf curling and stunting, and promotes sooty mold growth by honeydew deposition. Traditional chemical control using broad-spectrum insecticides often leads to resistance development and negative effects on beneficial organisms.

3. Spirotetramat

3.1 Spirotetramat

3.1.1. Chemical structure

In 2002, Bayer Crop Science launched spirodiclofen, the first member of the ketoenol group, a new acaricide with unique symptomology of poisoning, indicating a totally novel biochemical mode of action (Wachendorff *et al*., 2002; Nauen, 2005). Soon after, the second ketoenol was introduced, spiromesifen, acaricide and insecticide active against spider mites and whiteflies (Nauen *et al*., 2002 and 2005). Recently introduced the third cyclic ketoenol, spirotetramat, is an insecticide proved as effective against whiteflies, aphids and other homopteran pests (Nauen *et al*., 2008). These compounds having unique mode of action called insect lipid biosynthesis inhibitor.

International Union for Pure and Applied Chemistry (IUPAC) Name	:	*cis*-4-(ethoxycarbonyloxy)-8-methoxy-3-(2,5-xylyl)-1-azaspiro[4.5]dec-3-en-2-one
Chemical Abstracts Service (CAS) Name	:	*cis*-3-(2,5-dimethylphenyl)-8-methoxy-2-oxo-1-azaspiro[4.5]dec-3-en-4-yl ethyl carbonate
Formula	:	$C_{21}H_{27}NO_5$

3.1.2. Mechanism of action

Spirotetramat is a lipid biosynthesis inhibitor (Nauen *et al*., 2006), similar to the tetronic acid derivatives spirodiclofen (Envidor®) and spiromesifen (Oberon®) (Wachendorff *et al*., 2000 and 2002; Nauen *et al*., 2002, 2003 and 2005). Due to its mode of action spirotetramat is particularly effective against juvenile stages of sucking pests. In the case of female adults the compound significantly reduces fecundity and fertility. Spirotetramat also has unique translocation properties; after foliar uptake the insecticidal activity is translocated within the entire vascular system, *i.e.* it moves upwards and downwards through its translocation in the xylem and phloem, respectively. Such properties even allow the control of hidden pests such as root aphids and the protection of new shoots or leaves appearing after foliar application.

4. Effectiveness of spirotetramat against sucking pests

Spirotetramat, a spirocyclic tetramic acid derivative (Bretschneider *et al*., 2007), is a fully systemic insecticide. The compound is intended for worldwide use on pome fruits, stone fruits, citrus, grapes, almonds, nuts, hops, tea, vegetables, cotton and tropical fruits. The efficacy of spirotetramat ranges from good to excellent on a wide spectrum of sucking pests including aphids (*Aphis* spp., *Myzus* spp., *Dysaphis* spp., *Toxoptera* spp and *Phorodon humuli* Schrank), Pemphigidae (*Eriosoma* spp. and *Pemphigius* spp.), root aphids (*Phylloxera* spp.), psyllids (*Psylla* spp. and *Paratrioza cockerelli* Sulc), scales (*Ceroplastes* spp., *Pulvinaria* spp., *Aonidiella* spp., *Quadraspidiotus* spp and *Orthezia praelonga* Douglas), mealy bugs (*Pseudococcus* spp., *Planococcus* spp.) and whiteflies *(Bemisia* spp. and *Trialeurodes vaporariorum* Westwood)

(Nauen *et al*., 2008). Vinothkumar *et al*. (2008a) stated that the spirotetramat 150 OD at 75 g a.i. ha^{-1} was highly effective in checking the population of aphid, *A. gossypii* and treated plots registered a population of 7.0, 3.3 and 0.9 aphids three $leaves^{-1}$ in the first, second and third trials, respectively in cotton crop. Bruck *et al*. (2009) showed that populations of mealybugs, psyllids, sweet potato whitefly (*B. tabaci*) and a number of aphid species were suppressed after applying spirotetramat.

4.2 Reduction in Aphid Population

In the referenced investigation, spirotetramat 150 OD at recommended doses (e.g., 75 g a.i./ha) resulted in a marked reduction in aphid counts over multiple sprays. After the first, second, and third applications, aphid numbers on treated plants were significantly lower than on untreated plants, illustrating consistent control across sprays. In comparison, imidacloprid often performed similarly, indicating the competitive efficacy of spirotetramat in field conditions. (Masu journal)

4.3 Sublethal Effects and Population Dynamics

Beyond direct mortality, spirotetramat exhibits sublethal effects by disrupting aphid development and reproduction. Studies on A. gossypii populations exposed to spirotetramat reported suppressed fecundity, extended developmental periods, and reduced reproductive rates at sublethal concentrations. This contributes to long-term population suppression, not just immediate knockdown.(Pubmed)

5. Integrated Pest Management (IPM) Implications

Spirotetramat's systemic and growth-regulating properties make it suitable for inclusion in IPM programs. Its selective action against aphids while having relatively lower impacts on many natural enemies (when used appropriately and timed properly) enhances its compatibility with biological control agents and cultural practices. Continued rotation with other modes of action helps delay resistance development in aphid populations.

6. Advantages and Limitations

6.1 Advantages

- Systemic action ensures protection of new plant growth.
- Effective against multiple generations due to IGR properties.
- Can reduce aphid fecundity and slow population growth.

- Often compatible with IPM strategies.

6.2 Limitations

- Risk of resistance buildup if overused without rotation.
- Sublethal exposures can sometimes induce metabolic changes in aphids affecting sensitivity.(Pubmed)

7. Conclusions and Future Directions

Spirotetramat 150 OD has demonstrated reliable bioefficacy against *Aphis gossypii* in brinjal and related crops, reducing both immediate aphid populations and long-term reproductive potential. Its incorporation into brinjal pest management can significantly enhance control of aphids when used as part of a balanced strategy including biological control and other cultural practices. Future research should focus on optimizing spray timing, dose, and integration with natural enemies to maximize sustainable aphid management while minimizing resistance development.

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Spirotetramat 150 OD at recommended doses significantly reduced aphid populations in field studies, comparable to imidacloprid. Masu journal

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Aphids may exhibit metabolic responses at high exposure levels. Pubmed

ECO-INTELLIGENT TRAP CROPPING: A SUSTAINABLE APPROACH TO SMART PEST MANAGEMENT

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ABSTRACT

Eco-intelligent trap cropping, a time-tested ecological approach, is gaining renewed importance as a sustainable component of Integrated Pest Management (IPM). This strategy utilizes specific crops that are more attractive to insect pests than the main crop, thereby diverting pest populations and reducing crop damage. Beyond simple pest diversion, eco-intelligent cropping systems integrate ecological principles and precision agronomy to enhance system resilience, conserve natural enemies, and minimize pesticide dependence. The effectiveness of trap crops within an eco-intelligent framework depends on their inherent characteristics, pest behaviour, spatial arrangement, and synchronization with the main crop. Studies have shown that crops like squash around tomato or cantaloupe around cotton effectively attract pests such as whiteflies, lowering infestation and virus incidence. Moreover, eco-intelligent trap cropping provides multiple ecological services such as supporting natural enemy populations and improving agro-ecosystem stability. The success of these systems lies in their knowledge-intensive design, considering crop–pest interactions and local agro-climatic factors. By combining traditional ecological wisdom with modern precision techniques, eco-intelligent trap cropping emerges as a promising, smart, and sustainable solution to pest management, aligning with the goals of climate-resilient and environmentally responsible agriculture.

Keywords: Eco-intelligent cropping, Trap crops, Sustainable pest management, Pest diversion, Ecological resilience

Introduction

Trap cropping is a traditional approach to insect pest management that has gained considerable attention in recent years due to increasing concerns over the overdependence on chemical pesticides. Excessive use of pesticides has resulted in environmental contamination, pest resistance, and adverse effects on human and animal health, emphasizing the urgent need for sustainable pest management strategies. Consequently, there is growing interest in environmentally safe, economically viable, and eco-intelligent crop protection systems that reduce chemical inputs while sustaining crop productivity.

Trap crops are widely recognized as an effective component of integrated pest management (IPM) systems, offering multiple agronomic and environmental advantages (Sharma *et al*., 2019). By attracting insect pests away from the main crop, trap cropping significantly reduces crop damage and lowers reliance on chemical pesticides in a cost-effective manner (Lu *et al*., 2009). Due to the limitations and challenges associated with conventional pest control methods, farmers are increasingly adopting this strategy.

The present paper highlights various crops suitable for use as insect trap crops in farming systems. In organic production systems, pest populations can be effectively managed by collecting insects using sweep nets instead of applying pesticides. Sarkar *et al*. (2018) note that since the 1930s, numerous successful cases of trap cropping have been documented, leading to substantial reductions in pesticide use, particularly in developing countries. Furthermore, Sharma *et al*. (2019) report extensive evidence of successful trap crop utilization since the late twentieth century across a wide range of crops, including cotton, soybean, potato, rapeseed, beans, rice, sorghum, and vegetable crops. According to Tillman and Cottrell (2012), trap cropping involves cultivating highly attractive plant species to concentrate and retain insect pests, thereby minimizing their infestation of the main crop.

Eco-Intelligent Trap Cropping

Eco-intelligent trap cropping is a sustainable pest management strategy in which specific crops are grown alongside the main crop to attract and divert insect pests, protecting the primary crop from damage. Trap crops can be conventional, genetically engineered, or dead-end types that attract pests but do not support their reproduction, effectively reducing pest populations. This approach can be implemented using various spatial and temporal arrangements, such as strip planting, perimeter planting, sequential planting, or push–pull systems, depending on the cropping system and pest behaviour.

The strategy is environmentally safe, cost-effective, and farmer-friendly, reducing reliance on chemical pesticides while promoting soil health and ecosystem stability. By integrating ecological principles with practical crop management, eco-intelligent trap cropping enhances crop protection, improves biodiversity, and supports sustainable and resilient agricultural systems. It is particularly suitable for organic and low-input farming, offering a holistic solution for eco-smart pest management (Panwar *et al*., 2021).

Modalities of Trap Cropping

Trap cropping modalities are broadly classified based on plant traits and their spatial or temporal deployment. Other approaches, such as biological and semiochemical assistance, may not fit strict classifications but significantly enhance effectiveness. In many cases, successful trap cropping involves combining multiple modalities (Shelton and Badenes-Perez, 2006). The modalities of trap cropping relevant to integrated pest management are clearly outlined in Table 1.

Table 1. Modalities of trap cropping in integrated pest management

Basis of Classification	Modality	Description	Remarks
Based on Trap Crop Plant Characteristics	**Conventional Trap Cropping**	Uses naturally attractive crops to divert pests away from the main crop.	Squash attracting squash bugs and beetles
	Genetically Engineered Trap Cropping	Employs genetically modified crops that attract pests while protecting the main crop.	Bt potato used as a trap crop
	Dead-end Trap Cropping	Trap crops attract pests but do not allow completion of their life cycle, acting as a pest sink.	Yellow rocket trapping diamondback moth
Based on Deployment of Trap Crop	**Perimeter Trap Cropping**	Trap crops planted along field borders to intercept pests before entering the main crop.	Squash around tomato to attract whiteflies and beetles
	Sequential Trap Cropping	Trap crops planted earlier or later than the main crop to	Early-planted sunflower attracting

		coincide with peak pest activity.	bollworms before cotton
	Multiple Trap Cropping	Use of more than one trap crop species to manage multiple pests or life stages.	Combination of trap crops in pest-diverse systems
	Push–Pull Strategy	Combines repellent (push) plants within the crop and attractive (pull) plants on borders.	Desmodium (push) + Napier grass (pull) for maize stem borer in Kenya

Modalities based on the trap crop plant characteristics

Trap cropping can be implemented using different modalities based on the characteristics of the trap plants and their interaction with pests (Fig. 1). Conventional trap cropping involves the use of naturally attractive crops to divert pests away from the main crop. For example, squash can be planted to attract squash bugs and beetles, thereby reducing damage to neighboring crops. Genetically engineered trap cropping employs modified crops, such as Bt potatoes, which are designed to attract pests while protecting the primary crop, offering a precise and targeted pest management strategy (Devi *et al*., 2021). Dead-end trap cropping uses plants that attract pests but do not allow them to complete their life cycle, effectively acting as a pest sink. An example is yellow rocket, which attracts diamondback moths but prevents their population from increasing, thus safeguarding the main crop. These diverse modalities provide farmers with flexible, effective, and eco-friendly options for integrated pest management (Badenes et al., 2024).

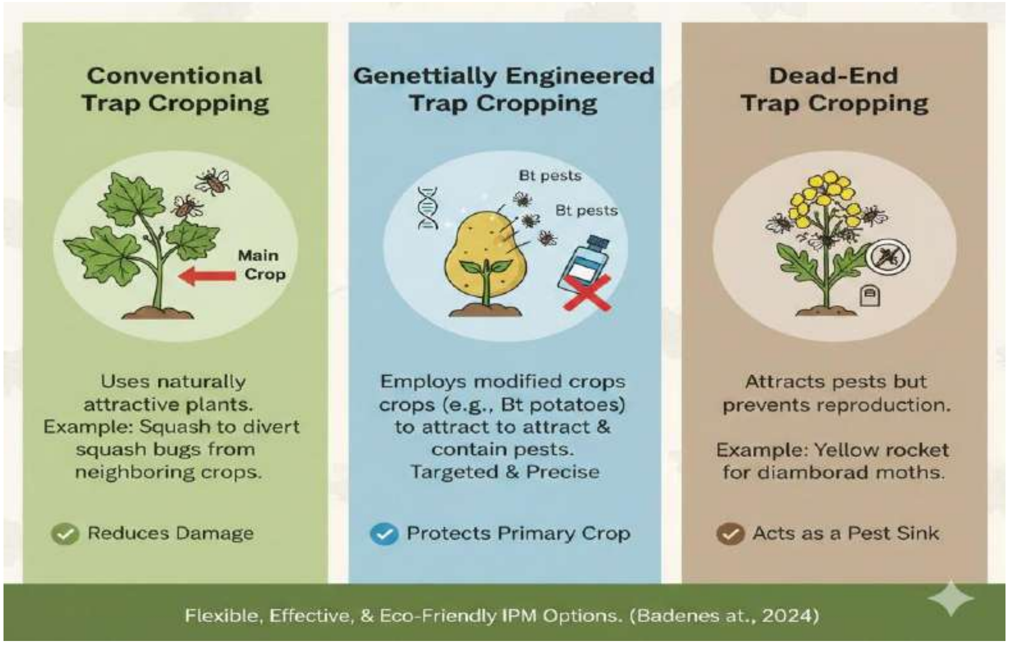

Figure 1. Modalities of trap cropping in integrated pest management

Modalities based on the deployment of the trap crop

Trap cropping should be understood within the broader framework of landscape ecology, where agroecosystems consist of dynamic habitat mosaics that vary over time in their suitability for insect pests and their natural enemies. From a trap cropping perspective, key landscape features include the spatial arrangement of vegetation patches, such as their size, distribution, configuration, and connectivity, which strongly influence insect–host plant interactions. Based on deployment patterns within this landscape context, the main trap cropping modalities include perimeter, sequential, multiple, and push–pull systems.

Perimeter trap cropping

Perimeter trap cropping involves planting highly attractive crops along field borders to intercept insect pests before they reach the main crop. The border crops act as a barrier, attracting pests due to their growth stage or plant traits and concentrating them at field edges. This allows easy monitoring and targeted pest management, reducing pest pressure and the need for whole-field pesticide application. For example, squash planted around tomato fields attracts whiteflies and beetles away from tomatoes. This method is cost-effective, environmentally friendly, and widely used in vegetable cropping systems (Lalita et al., 2020).

Sequential trap cropping

Sequential trap cropping involves planting trap crops earlier or later than the main crop to coincide with peak pest activity. Early-planted trap crops serve as initial hosts for emerging pests, thereby preventing their establishment in the main crop. This strategy is effective against pests with predictable seasonal occurrence. For instance, early-planted sunflower attracts bollworms before cotton establishment, reducing pest buildup. Sequential trap cropping is adaptable across regions and supports sustainable pest management by minimizing chemical use (Reddy, 2017).

Multiple trap cropping

Multiple trap cropping uses more than one trap crop species within a field to target different pest species or life stages. The use of diverse attractive hosts enhances pest diversion and reduces pressure on the main crop. This system increases plant diversity, supports beneficial insects, and improves ecological stability. Multiple trap cropping is especially useful in pest-diverse agro-ecosystems and is well suited for organic and low-input farming systems, reducing reliance on synthetic pesticides (Cotes *et al*., 2018).

Push–Pull Strategy

The push–pull strategy is an eco-friendly pest management approach that manipulates insect behavior using repellent and attractive plants. In this system, push plants such as Desmodium are intercropped with the main crop to repel pests through the release of natural chemicals that disrupt host-finding. Desmodium also improves soil fertility and suppresses weeds (Chatterjee and Kundu, 2022).

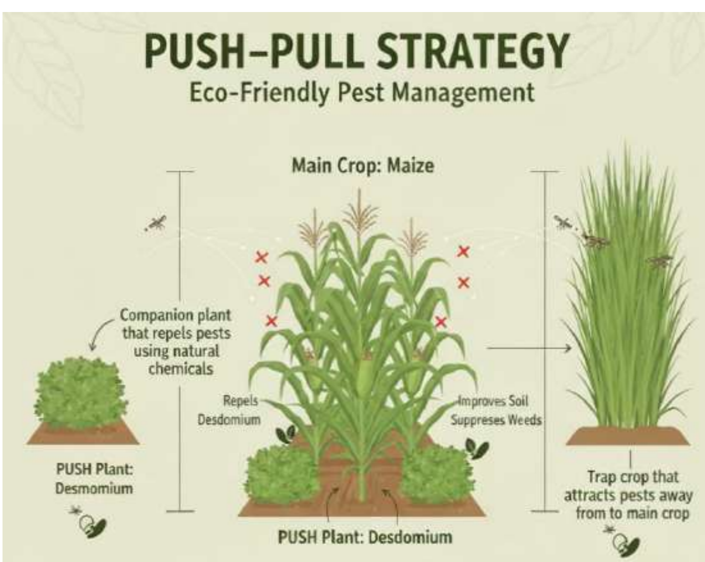

Figure 2. The push–pull strategy is an effective pest management approach.

Pull plants, such as Napier grass, are planted around the field borders to attract pests away from the main crop. Napier grass traps pests by encouraging egg laying, while larvae fail to survive, thereby reducing pest populations. A successful example is the use of Desmodium (push) and Napier grass (pull) to manage maize stem borers in Kenya. This strategy reduces pesticide use, improves crop yield, and supports sustainable and environmentally safe pest management.

Factors determining the success of trap cropping systems

From a practical and commercial perspective, only a limited number of trap cropping systems have been successfully implemented in agricultural and forestry settings. The success of trap cropping largely depends on the interaction between trap crop characteristics, their deployment, and the ecology and behaviour of the target insect pest. Neither insect traits nor trap crop features alone can predict success; rather, their combined effects along with practical field considerations determine effectiveness (Sarkar *et al*., 2018).

Key insect-related factors include the life stage targeted, mobility, migratory behaviour, and host-finding mechanisms. Insects with strong directional movement and aggregation behaviour, such as many Coleoptera and Lepidoptera, are more suitable for trap cropping than insects that disperse passively. The spatial arrangement of trap crops must align with pest colonization patterns, with perimeter trap cropping being effective against insects entering fields from outside (Parker *et al*., 2016). Trap crop attractiveness, field layout, and the proportion of trap crop area strongly influence pest arrestment and retention. Overall, successful trap cropping requires an optimal match between insect behaviour, trap crop attractiveness, and deployment strategy (Vlahova, 2021).

Challenges of trap cropping

- Trap cropping is often species-specific, providing effective control only for certain insect pests.
- It may involve higher initial costs than pesticide use due to additional inputs such as seeds and labour.
- The approach is knowledge-intensive, requiring an understanding of pest behaviour, crop stages, and field layout.

- Success can be variable, depending on agro climatic conditions and management practices.
- Effective implementation requires careful planning and farmer cooperation, especially in neighbouring fields.
- Limited awareness and technical guidance can restrict adoption.
- Timely monitoring and management of trap crops are essential to prevent pest spill over (Mir *et al*., 2022).

Conclusion

Trap cropping is an eco-friendly and cost-effective strategy for integrated pest management. By diverting pests to attractive trap crops, it reduces crop damage and pesticide use while supporting biodiversity and soil health. Its success depends on selecting appropriate trap crops, proper deployment, and understanding pest behaviour. Modalities like perimeter, sequential, multiple, and push–pull systems offer flexible solutions for various crops and pests. Although knowledge-intensive and requiring careful management, trap cropping provides a sustainable and resilient approach to modern agriculture.

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NATURE'S SHIELD FOR ECO-FRIENDLY SEED STORAGE PEST CONTROL

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Introduction

Seed storage is a critical component of agricultural sustainability, ensuring the availability of high-quality planting material and safeguarding food security. However, stored seeds are highly susceptible to damage by a wide range of pests, particularly insects, mites, rodents, and storage fungi. Globally, post-harvest losses due to storage pests account for 10–30 percent of total seed and grain production, with even higher losses in tropical and subtropical regions. Conventional pest control practices in seed storage have largely relied on synthetic fumigants and chemical insecticides. While effective, these chemicals raise serious concerns related to toxic residues, resistance development, environmental pollution, and risks to human health. In response to these challenges, eco-friendly seed storage pest control has gained prominence. "Nature's shield" represents a holistic approach that harnesses botanical, biological, physical, and traditional methods to protect stored seeds in a sustainable and environmentally benign manner.

Major Seed Storage Pests and Their Impact

Seed storage environments provide favorable conditions for the development and multiplication of a wide range of pests, resulting in substantial post-harvest losses. Among the various biotic constraints affecting stored seeds, insect pests are the most destructive and economically significant. These pests not only cause direct physical damage to seeds but also indirectly promote secondary infestations by mites and microorganisms. The nature and extent of damage depend on pest species, storage duration, seed moisture content, and prevailing environmental conditions such as temperature and relative humidity. Understanding the major seed storage pests and their impact is essential for designing effective and eco-friendly management strategies.

Storage insect pests are broadly classified into primary and secondary pests based on their ability to infest sound seeds. Primary pests such as *Sitophilus oryzae* (rice weevil), *Sitophilus zeamais* (maize weevil), *Callosobruchus chinensis* and *Callosobruchus maculatus* (pulse beetles), and *Rhyzopertha dominica* (lesser grain borer) are capable of attacking intact and healthy seeds. Adult insects bore into the seed coat and lay eggs inside the grain, and the developing larvae feed internally on the endosperm and embryo. This internal feeding results in hollowed seeds, significant loss of seed weight, and severe reduction in germination capacity. In seed lots meant for planting, damage to the embryo leads to abnormal seedlings or complete failure of germination, thereby compromising crop establishment.

Secondary pests such as *Tribolium castaneum* (red flour beetle), *Oryzaephilus surinamensis* (saw-toothed grain beetle), and *Cryptolestes* species generally infest broken, cracked, or previously damaged seeds. Although they may not penetrate sound seeds, their feeding activity accelerates the deterioration process by producing large quantities of frass, cast skins, and metabolic heat. These conditions increase seed temperature and moisture, creating a microenvironment conducive to fungal growth. Secondary pests also impart unpleasant odors and discoloration to stored seeds, reducing their market and sowing value.

Mites represent another important group of storage pests, particularly under conditions of high humidity and poor ventilation. Species such as *Acarus siro* infest seeds externally, causing surface damage, heating, and discoloration. Heavy mite infestation leads to seed clumping and dust formation, adversely affecting seed handling and sowing operations. Moreover, mites act as vectors for storage fungi, further aggravating seed deterioration.

Storage fungi, especially species of *Aspergillus* and *Penicillium*, often develop as secondary invaders following insect or mite damage. These fungi degrade seed tissues, reduce seed vigor, and may produce harmful mycotoxins that pose serious health risks to humans and livestock. In addition, rodent pests contribute to direct seed losses through feeding and cause contamination with hair, urine, and feces, rendering stored seed lots unfit for use.

Collectively, seed storage pests cause quantitative losses through reduction in seed weight and qualitative losses through diminished germination, vigor, and storability. The cumulative impact of these pests results in poor field emergence, reduced crop yield, and significant economic losses. Therefore, effective management of major seed storage pests is a critical component of sustainable seed storage systems and forms the foundation for eco-friendly and integrated pest control strategies.

Drawbacks of Chemical-Based Seed Storage Pest Management

Chemical fumigants such as phosphine and methyl bromide have been widely used for controlling storage pests. However, continuous use has resulted in the evolution of resistant pest populations, particularly in phosphine-resistant beetles. Chemical residues on seeds pose risks to farmers, seed handlers, and consumers, and may negatively influence seed physiology. Environmental contamination, ozone depletion concerns, and strict regulatory restrictions have further limited the use of many synthetic fumigants. These limitations highlight the necessity of shifting toward eco-friendly and sustainable alternatives that are compatible with organic and low-input agricultural systems.

Dependence on Synthetic Fumigants and Insecticides: Chemical-based seed storage pest management has traditionally relied on synthetic fumigants such as phosphine and, earlier, methyl bromide, as well as residual insecticides. Continuous dependence on these chemicals has created an unsustainable management system, as repeated applications are required to maintain effectiveness. This overreliance increases operational costs and reduces the long-term reliability of chemical control measures.

Development of Pest Resistance: One of the most serious drawbacks of chemical pest control is the rapid development of resistance in major storage pests. Insects such as *Sitophilus* spp. and *Rhyzopertha dominica* have developed resistance to commonly used fumigants, particularly phosphine, due to prolonged and indiscriminate use. Resistant pest populations survive treatments and multiply, leading to control failures and increased infestation levels during storage.

Residual Toxicity and Seed Safety Concerns: Chemical fumigants and insecticides often leave toxic residues on stored seeds. These residues pose health risks to seed handlers, farmers, and consumers, especially when treated seeds are mistakenly used for food or feed. In seed storage, chemical residues may also interfere with seed physiology, affecting germination, enzyme activity, and seedling vigor, thereby reducing the overall planting value of the seeds.

Environmental Pollution and Ecological Imbalance: Chemical pest control contributes to environmental contamination through air, soil, and water pollution. Persistent chemical residues disrupt soil microflora and harm non-target organisms, including beneficial insects and microorganisms. The use of certain fumigants has also been associated with atmospheric pollution, leading to global environmental concerns and stricter regulatory controls.

Human Health Hazards: Exposure to chemical fumigants during storage, handling, and application poses serious health risks. Inadequate safety measures and lack of protective equipment can lead to acute poisoning, respiratory problems, skin irritation, and long-term health complications among workers. These risks are particularly severe in developing countries where awareness and infrastructure for safe pesticide handling are limited.

Regulatory Restrictions and Limited Acceptability: Many chemical fumigants are subject to strict regulations or bans due to their environmental and health impacts. For instance, the phase-out of methyl bromide under international agreements has reduced available chemical options for storage pest management. Increasing regulatory scrutiny limits flexibility and creates challenges for seed producers who rely heavily on chemical control.

Incompatibility with Organic and Sustainable Agriculture: Chemical-based pest management is incompatible with organic farming standards and sustainable agriculture principles. The use of synthetic chemicals contradicts consumer demand for residue-free seeds and environmentally responsible practices. This incompatibility restricts market access and reduces the acceptability of chemically treated seeds in organic and eco-conscious farming systems.

Negative Impact on Integrated Pest Management Programs: Excessive use of chemicals undermines integrated pest management strategies by disrupting natural enemy populations and discouraging the adoption of preventive and non-chemical approaches. Chemical dominance often replaces holistic pest management planning, reducing system resilience and increasing vulnerability to future pest outbreaks.

Botanical Protectants: Plant-Derived Natural Defenses

Botanical protectants constitute one of the most effective components of nature's shield in seed storage. Plants produce a wide range of secondary metabolites with insecticidal, repellent, antifeedant, and growth-regulating properties. Neem (*Azadirachta indica*) is the most extensively studied botanical, with neem seed kernel powder and neem oil disrupting insect feeding, molting, and reproduction. Essential oils from eucalyptus, clove, citronella, peppermint, and lemongrass exhibit strong fumigant and repellent activity against storage insects. Sweet flag (*Acorus calamus*) rhizome powder has long been used in traditional storage systems due to its toxicity against beetles. Botanical protectants are biodegradable, locally available, and generally safe to non-target organisms when applied at recommended dosages, making them ideal for eco-friendly seed storage.

Concept and Importance of Botanical Protectants: Botanical protectants refer to pest control substances derived from plants that possess natural defensive chemicals capable of suppressing or repelling insect pests. In the context of seed storage, botanical protectants serve as an eco-friendly alternative to synthetic pesticides, offering effective pest management while preserving seed quality and environmental safety. Plants synthesize a wide array of secondary metabolites such as alkaloids, terpenoids, phenolics, and essential oils that act as toxicants, repellents, antifeedants, or growth regulators against storage insects. The use of botanicals aligns well with sustainable agriculture, organic farming, and integrated pest management principles, making them an important component of nature-based seed storage pest control.

Neem (Azadirachta indica): A Multifunctional Botanical Protectant: Neem is one of the most widely used botanical protectants in seed storage pest management. Various neem products such as neem seed kernel powder (NSKP), neem oil, and neem leaf powder exhibit strong insecticidal properties. The active compound azadirachtin disrupts insect feeding behavior, molting, and reproduction by interfering with hormonal regulation. In stored seeds of cereals and pulses, neem-based treatments effectively suppress infestations of *Sitophilus* spp. and *Callosobruchus* spp. without adversely affecting seed germination. Neem products are biodegradable, non-toxic to humans at recommended doses, and provide prolonged protection during storage, making them highly suitable for farmer-level application.

Essential Oils as Natural Fumigants and Repellents: Essential oils extracted from aromatic plants act as powerful natural fumigants and repellents against storage pests. Oils derived from clove (*Syzygium aromaticum*), eucalyptus (*Eucalyptus globulus*), citronella (*Cymbopogon nardus*), lemongrass (*Cymbopogon citratus*), and peppermint (*Mentha piperita*) have demonstrated high efficacy against insects such as *Tribolium castaneum* and *Rhyzopertha dominica*. These essential oils affect the insect nervous system, leading to paralysis and mortality, while also repelling adult insects and preventing oviposition. Due to their volatile nature, essential oils provide rapid action and are particularly useful in sealed or semi-sealed storage structures.

Sweet Flag (Acorus calamus) and Other Traditional Botanicals: Sweet flag rhizome powder (*Acorus calamus*) has been traditionally used in many parts of India for protecting stored grains and seeds. The bioactive compound β-asarone exhibits strong insecticidal and repellent properties against storage pests. Application of sweet flag powder effectively reduces infestation by rice weevil and pulse beetles while maintaining seed viability. Other traditionally used botanicals include tobacco leaves (*Nicotiana tabacum*), custard apple seed powder (*Annona squamosa*), and pongamia (*Pongamia pinnata*) seed oil. These plant materials act through contact toxicity, feeding deterrence, and disruption of insect development.

Mode of Action of Botanical Protectants: Botanical protectants act through multiple mechanisms, which reduce the likelihood of resistance development. They may cause direct toxicity by disrupting the insect nervous system, interfere with digestion by inhibiting enzyme activity, or act as antifeedants and oviposition deterrents. Some botanicals inhibit egg hatching and larval development, thereby breaking the pest life cycle. The presence of multiple active compounds in plant extracts ensures broad-spectrum activity and enhances pest suppression in storage environments.

Biological Control Agents in Stored Seed Protection

Biological control involves the use of natural enemies to suppress pest populations in storage ecosystems. Parasitoids such as *Anisopteromalus calandrae* and *Dinarmus basalis* effectively parasitize larvae and pupae of bruchids and weevils in stored seeds. Predators and parasitoids help maintain pest populations below damaging levels without chemical intervention.

Microbial agents, particularly entomopathogenic fungi like *Beauveria bassiana* and *Metarhizium anisopliae*, infect storage insects and cause mortality through cuticle penetration and toxin production. These biological agents are eco-friendly, residue-free, and compatible with integrated pest management strategies. Their use represents a promising long-term solution for sustainable seed storage pest control.

Parasitoids as Natural Regulators of Storage Insects: Parasitoids are among the most effective biological control agents used in stored seed protection. These insects lay their eggs on or inside the immature stages of storage pests, leading to the eventual death of the host. *Anisopteromalus calandrae* is a well-known parasitoid of internal feeders such as *Sitophilus* spp. and *Rhyzopertha dominica*. The female parasitoid locates infested grains and deposits eggs on pest larvae or pupae developing inside the seeds. Similarly, *Dinarmus basalis* is highly effective against pulse beetles (*Callosobruchus* spp.) in stored legumes. These parasitoids significantly reduce pest populations by interrupting their life cycle and preventing population buildup during prolonged storage.

Predatory Insects in Seed Storage Ecosystems: Although predators are less commonly used in stored seed environments compared to open field systems, certain predatory insects contribute to pest suppression. Predators feed directly on eggs, larvae, or adults of storage pests. Species such as *Xylocoris flavipes*, a predatory bug, actively feed on eggs and larvae of beetles like *Tribolium castaneum* and *Oryzaephilus surinamensis*. By reducing early developmental stages, predators help limit infestation intensity and complement the action of parasitoids in integrated storage pest management systems.

Entomopathogenic Fungi as Microbial Biocontrol Agents: Entomopathogenic fungi represent a promising group of biological control agents for stored seed protection. Fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* infect storage insects through the cuticle, proliferate inside the host body, and cause death. These fungi are effective against a wide range of storage pests including weevils, beetles, and flour insects. Application of fungal spores in storage structures or as seed protectants provides prolonged control without leaving toxic residues. Their ability to persist under storage conditions enhances their usefulness in eco-friendly pest management.

Bacterial and Viral Biopesticides: Certain bacterial agents also play a role in biological control of storage pests. *Bacillus thuringiensis* (Bt), known for its insecticidal crystal proteins, is effective against larvae of specific beetle species when ingested. Although its use in stored seed systems is limited compared to field crops, Bt formulations offer a targeted and environmentally safe option. Viral agents, such as insect-specific nucleopolyhedroviruses, have also shown potential, though their application in storage environments remains largely experimental.

Physical Methods as Eco-Friendly Pest Barriers

Physical methods of pest control are among the safest and most environmentally benign strategies used in seed storage systems. These methods rely on manipulating physical factors such as temperature, atmosphere, moisture, and mechanical exclusion to create conditions that are unfavorable for pest survival and reproduction. Unlike chemical control measures, physical methods do not leave toxic residues, do not induce pest resistance, and pose no risk to seed handlers or consumers. Their eco-friendly nature makes them highly suitable for sustainable agriculture, organic seed production, and long-term seed conservation. Physical pest barriers are particularly effective when used as preventive measures, forming the first line of defense against storage pests.

Hermetic Storage and Modified Atmosphere Techniques: Hermetic storage is one of the most effective physical methods used for controlling storage pests. It involves storing seeds in airtight containers such as metal bins, sealed plastic drums, glass jars, or triple-layer hermetic bags. These systems restrict oxygen availability while increasing carbon dioxide levels inside the container. Storage insects such as *Sitophilus* spp., *Callosobruchus* spp., and *Rhyzopertha dominica* rely on oxygen for respiration, and reduced oxygen levels suppress feeding, development, and reproduction, eventually leading to mortality. Hermetic storage not only controls insects but also prevents moisture ingress, thereby reducing fungal growth and maintaining seed quality over extended periods.

Temperature Manipulation as a Pest Control Strategy: Temperature plays a critical role in the survival and development of storage pests. High-temperature treatments, such as solarization, expose seeds to elevated temperatures for a short duration, effectively killing insects at all life stages. Solar heating is achieved by placing seeds in transparent polyethylene sheets or containers under direct sunlight, raising internal temperatures to lethal levels. Conversely, low-temperature storage, including cold storage and refrigeration, inhibits insect activity and development. Exposure to temperatures below the developmental threshold prevents egg hatching and larval growth. Temperature manipulation is particularly useful for high-value seeds and germplasm conservation where chemical treatments are undesirable.

Moisture Control and Drying Techniques: Seed moisture content is a critical factor influencing pest infestation. Most storage insects and fungi thrive at higher moisture levels. Drying seeds to safe moisture limits before storage significantly reduces the risk of infestation. Sun drying, shade drying, and mechanical drying are commonly used methods to achieve optimum moisture levels. Proper moisture control not only limits insect activity but also prevents fungal growth and mycotoxin contamination. Maintaining low humidity inside storage structures through ventilation and moisture-proof packaging further enhances the effectiveness of physical pest barriers.

Mechanical Cleaning and Grading: Mechanical cleaning and grading are simple yet highly effective physical methods for reducing storage pest infestation. These practices involve removing broken, damaged, and infested seeds, as well as dust and debris that serve as breeding grounds for secondary pests. Sieving, winnowing, and mechanical graders reduce the initial pest load and prevent the spread of infestation within stored seed lots. Clean seeds with uniform size and integrity are less attractive to pests and have better storability. Mechanical cleaning also improves aeration and facilitates uniform application of other eco-friendly protectants.

Structural and Architectural Pest Barriers: The design and construction of storage structures play a significant role in preventing pest entry and infestation. Properly sealed storage facilities with smooth walls, sealed cracks, and tight-fitting doors restrict insect and rodent access. Raised platforms, rodent guards, and mesh screens further enhance physical exclusion. The use of pest-proof containers and improved granaries reduces dependence on chemical treatments. Structural barriers are particularly important for long-term storage facilities such as seed warehouses and community seed banks.

Use of Light and Radiation-Based Techniques: Light manipulation and radiation-based techniques are emerging physical methods for pest control in stored seeds. Ultraviolet light and controlled irradiation have been explored for their ability to sterilize insects and inhibit reproduction. Low-dose irradiation effectively kills insect eggs and larvae without significantly affecting seed viability. Although these techniques require specialized equipment and infrastructure, they offer residue-free and highly effective pest control options, particularly for quarantine and seed export purposes.

Use of Natural Inert Materials

Natural inert materials provide an economical and non-toxic approach to pest management in stored seeds. Diatomaceous earth, composed of fossilized diatoms, acts as an abrasive desiccant that damages the insect cuticle, leading to dehydration and death. Ash, sand, lime, and clay have also been traditionally used as protectants by creating physical barriers that restrict insect movement and oviposition. These materials are especially valuable for small-scale farmers and community seed banks due to their low cost and ease of application. Their non-chemical mode of action reduces the risk of resistance development.

Diatomaceous Earth as a Desiccant Protectant: Diatomaceous earth (DE) is one of the most effective and widely studied inert materials used in seed storage. It is composed of fossilized remains of diatoms rich in silica. When storage insects such as *Sitophilus* oryzae, *Rhyzopertha dominica*, and *Tribolium castaneum* come into contact with DE, the fine particles abrade the insect cuticle and absorb protective wax layers. This leads to excessive water loss, dehydration, and eventual death of the insects. DE acts purely through physical means, making it safe, residue-free, and unlikely to induce pest resistance. When applied at recommended doses, it does not adversely affect seed germination or vigor.

Ash, Sand, and Clay as Traditional Barriers: Wood ash, sand, and clay have been traditionally used as inert protectants in stored seeds, especially in rural and indigenous storage systems. Ash creates an alkaline and abrasive environment that damages insect body surfaces and restricts movement. Sand and clay act as physical barriers by filling inter-seed spaces, thereby preventing insect penetration, oviposition, and mobility. These materials are particularly effective against pulse beetles (*Callosobruchus* spp.) when mixed with legume seeds. Their simplicity and ease of application make them popular in low-input storage systems.

Lime and Other Mineral Materials: Lime and other mineral powders have also been used to protect stored seeds from insect infestation. Lime alters the microenvironment by increasing alkalinity, which is unfavorable for insect survival. It also acts as a repellent and desiccant. However, careful application is required to avoid adverse effects on seed health. When properly used, mineral inert materials provide extended protection during storage.

Indigenous and Traditional Storage Practices

Indigenous knowledge systems offer valuable insights into sustainable seed storage pest management. Traditional practices such as mixing seeds with plant leaves, vegetable oils, cow dung ash, or storing seeds in smoked containers have been used for centuries. These methods rely on locally available resources and ecological understanding. Scientific validation of traditional practices enhances their credibility and encourages wider adoption. Integrating indigenous knowledge with modern eco-friendly technologies strengthens nature's shield against storage pests.

Influence of Eco-Friendly Methods on Seed Quality

One of the major advantages of nature-based pest control is its positive impact on seed quality. Botanical and biological protectants generally preserve seed viability, vigor, and physiological integrity. Unlike chemical fumigants, eco-friendly methods do not impair enzyme activity, membrane stability, or seed metabolism. Maintenance of high seed quality ensures better germination, uniform crop establishment, and improved yield performance. Thus, eco-friendly pest control contributes not only to pest suppression but also to seed health and productivity.

Integration of Nature's Shield into Sustainable Storage Systems

Maximum effectiveness of eco-friendly pest control is achieved through integration of multiple approaches. Combining sanitation, botanical protectants, biological agents, hermetic storage, and inert materials creates a multi-layered defense system against pests. This integrated approach aligns with the principles of Integrated Pest Management and organic agriculture. Such systems are resilient, adaptable, and capable of addressing pest challenges under changing climatic conditions.

Conclusion

Nature's shield for eco-friendly seed storage pest control offers a sustainable and holistic alternative to conventional chemical-based approaches in safeguarding stored seeds. By harnessing botanical protectants, biological control agents, physical methods, and natural inert materials, it is possible to effectively manage storage pests while preserving seed quality, environmental integrity, and human health. These nature-based strategies address the limitations of synthetic pesticides, including residue accumulation, resistance development, and ecological imbalance, making them particularly suitable for modern sustainable agriculture and organic seed systems.

The integration of multiple eco-friendly methods creates a resilient storage ecosystem in which pests are suppressed through preventive and non-toxic mechanisms rather than eradicated by chemicals. Such integrated systems not only reduce quantitative and qualitative post-harvest losses but also maintain seed viability, vigor, and storability. The reliance on locally available and biodegradable resources further enhances the economic feasibility and adaptability of these approaches, especially for small and marginal farmers, community seed banks, and decentralized seed storage facilities.

Moreover, nature's shield aligns with global efforts toward climate-resilient agriculture and food security by promoting safe, low-input, and environmentally responsible storage practices. Strengthening research, extension, and policy support will be essential for refining these technologies, standardizing their application, and encouraging widespread adoption. In the long term, eco-friendly seed storage pest control represents a vital step toward sustainable seed management systems that protect both agricultural productivity and ecological balance, ensuring the availability of healthy seeds for future generations.

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IMPACT OF INSECTICIDES ON ARTHROPOD BIODIVERSITY IN THE CHILLI ECOSYSTEM

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ABSTRACT

Chilli is an important commercial crop that is highly susceptible to insect pest infestation, resulting in widespread use of insecticides. While insecticides are effective in protecting yield, their intensive and indiscriminate application adversely affects arthropod biodiversity in the chilli ecosystem. Arthropods, including pests, natural enemies, pollinators, and other non-target organisms, play a vital role in maintaining ecological balance and ecosystem services. Insecticides cause direct mortality and sub-lethal effects on non-target arthropods, particularly predators and parasitoids, leading to reduced species diversity and disruption of biological control. Such disturbances often result in pest resurgence, secondary pest outbreaks, and increased dependence on chemical control. In addition, prolonged insecticide use alters community structure and functional biodiversity, threatening the sustainability of chilli agro-ecosystems. This chapter emphasizes the ecological consequences of insecticide use and highlights the need for integrated pest management approaches that promote selective insecticides and conservation of beneficial arthropods for long-term, sustainable chilli production.

Key words : chilli, biodiversity, predators, parasitoids and ecological

1.Introduction

Chilli (*Capsicum annum* L.) is considered as one of the most important commercial spice crops and is widely used universal spice, named as wonder spice. India is not only the largest producer but also the largest consumer of chilli in the world. Chillies are cultivated over an area of 784 (1000 ha) with an annual production of 1304 (1000MT) and productivity of 1.6 million tonnes per ha in India (Indian Horticulture Database-2013). It is cash crop so cultivated throughout the year and green and its red ripe dried stage used for their pungency, colour and other various ingredients in all culinary preparations of rich and poor also to give taste, colour and flavour.

Nutritionally, it is a rich source of vitamin A, B and C. Pungency in chillies is due to an alkaloid Capsaicin has medicinal properties and it dilating the blood vessels so as to prevents heart attack (Gill, 1989) This highly remunerative and useful crop is known to be attacked by over 20 insects and non-insect pests in India (Butani, 1976). Arthropod pests cause an overall reduction in yield up to 76.66 per cent in chilli (Ahmed *et al*., 2000). Major pests that attack chillies are aphids, *Myzus persicae* Sulzer, *Aphis gossypii*, yellow mite, *Polyphagotarsonemus latus* Banks and thrips *Scirtothrips dorsalis* Hood (Berke and Sheih, 2000).

Pesticides are the most common method deployed in controlling pests due to the quick response, easy to use, cost effective, efficient, notably amendable and reliable effectives against insects (Ressing, 1996). Unfortunately, improper uses of pesticides also killed the natural enemies which play an important role as biological control agents in reducing insect pest population in vegetable ecosystem. Pesticides have a negative impact on animal species distribution and biodiversity both within and sprayed fields. Plants, earthwarms, termites, ant colonies and birds have all been reported to be affected by pesticides use (Hall and Henry, 1992).

2. Arthropod Biodiversity in the Chilli Ecosystem

Regupathy and Ayyasamy (2013) reported 24 species of arthropods belonging to 14 different families occur on chillies in TamilNadu. The economically important pests are fruit borer, *Helicoverpa arimgera*(Hubner) , *Spotoptera litura* (Fabricius), sap feeders, chilli thrips, *S. dorsalis*, *M. persicae, A. gossypii, P.latus* and termite, *Odontotermus obesus* (Rambur). In Tamil Nadu, 11 species and 13 species of spider's fauna were recorded in fruit and vegetable crop ecosystems (Rajeswaren *et al*., 2005). Spiders are carnivorous arthropods, consuming a large number of preys and never damage the plants. They occupy a unique habitat and they live in all most all environments (Ghavami, 2007). Agricultural entomologists recognized the importance of spiders as a major factor which helps to regulate the population densities of insect pests (Nyffeler, 1994; Khan and Misra, 2006; Chatterjee *et al.,* 2009). Spiders are predaceous arthropods which largely feed on insects, their larvae and arthropod eggs.

3. Impact of insecticide on arthropod diversity

Vegetable ecosystem normally contains beneficial predators and parasites in numbers that provide partial to satisfactory pest control. In order to conserve natural enemies, care should be taken in the selection of appropriate insecticides for pest management to reduce the harmful effects caused by them. Present agricultural practices, exposure and susceptibility will determine the risk of an organism to suffer from side effects of pesticides (Jepson, 1989).

Srinivasababu and Sharma (2003) found that imidacloprid at 12.5 g a.i. ha^{-1} was the safest chemical against coccinellids compared to conventional insecticides like dimethoate and chlorpyriphos. Suganyakanna (2006) reported that acetamiprid influenced the species richness of spiders in cotton ecosystem. All the insecticidal treatments caused a short term reduction in the spider population of cotton and okra and later they tend to increase. Preetha (2008) reported that the application of imidacloprid 17.8 SL at 25 g a.i. ha^{-1} was found to be less toxic to natural enemies especially coccinellids and spiders. Preetha (2008) reported a maximum of nine species in the cotton ecosystem. The spider species, *O. javanus*, *Oxyopes rufisternum* Thorell, *Clubiona* sp. (cotton) and *Thomisus* sp. *Phidippus* sp. and *Clubiona* sp (okra) were predominant in the ecosystem observed. Amalin *et al*. (2009) reported that more individuals in the families Pompilidae, Scelionidae, Halictidae, Mutilidae, Apidae and Eulophidae belonging to the order Hymenoptera were collected in the non-sprayed plots. Similarly more individuals of the order Orthoptera were collected in the non-sprayed area than the sprayed area. They also observed higher number of spider mites and chalk mites in the sprayed area and a higher number of armored scales, eriophyid mite, butterfly and moth larvae in the non-sprayed area.

4. Indirect Effects on Arthropod Community Structure

4.1 Disruption of Biological Control

Elimination of predators and parasitoids results in **secondary pest outbreaks** and **pest resurgence**, particularly of sucking pests like aphids and mites, which reproduce rapidly.

4.2 Trophic Imbalance

Insecticides alter trophic relationships by selectively removing higher trophic levels. This simplification of the food web leads to **ecological instability** and reduced functional diversity.

4.3 Pest Resistance and Biodiversity Loss

Repeated insecticide use accelerates resistance development in chilli pests, necessitating higher doses or more toxic chemicals. This creates a feedback loop that further depletes arthropod biodiversity.

5. Effects of Different Insecticide Groups

Insecticide Group	Impact on Arthropod Biodiversity
Organophosphates & Carbamates	Highly toxic to predators, parasitoids, and pollinators
Synthetic Pyrethroids	Cause spider and coccinellid decline; induce mite resurgence
Neonicotinoids	Affect pollinators and soil arthropods; long residual toxicity
Insect Growth Regulators (IGRs)	Relatively selective but affect immature stages of beneficials
Botanical & Microbial Insecticides	Least disruptive; conserve natural enemies

6. Implications for Chilli Agro-ecosystem Sustainability

Loss of arthropod biodiversity due to insecticide misuse leads to:

- Increased production costs
- Greater pest management instability
- Environmental contamination
- Reduced resilience to climate variability

Sustainable chilli cultivation depends on maintaining a balanced arthropod community.

7. Mitigation Strategies

7.1 Integrated Pest Management (IPM)

- Use of economic threshold levels
- Conservation of natural enemies

- Need-based insecticide application

7.2 Use of Selective and Biorational Insecticides

- Neem-based products
- *Bacillus thuringiensis*
- Entomopathogenic fungi

7.3 Habitat Management

- Flowering refugia and border crops
- Reduced monocropping
- Avoidance of prophylactic sprays

8. Conclusion

Insecticides, while indispensable in chilli pest management, exert significant negative impacts on arthropod biodiversity when used indiscriminately. The decline of beneficial arthropods disrupts ecological balance, undermines natural pest control, and threatens long-term sustainability of chilli agro-ecosystems. Adoption of IPM and biodiversity-friendly pest management strategies is essential to reconcile productivity with ecological conservation.

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INTEGRATED MANAGEMENT OF FALL ARMYWORM (*Spodoptera frugiperda*) IN MAIZE AND OTHER CROPS

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ABSTRACT

The fall armyworm (*Spodoptera frugiperda* J.E. Smith) has emerged as one of the most destructive invasive insect pests threatening global agriculture, particularly maize-based production systems. Native to the Americas, the pest has rapidly expanded its geographical range across Africa and Asia, including India, causing severe yield losses and economic damage. Its polyphagous nature, high reproductive potential, migratory behaviour, and ability to develop resistance to insecticides have made its management highly challenging. In India, the pest has become a regular constraint in maize cultivation since its first report in 2018, compelling farmers to rely heavily on chemical control measures. Such practices have led to ecological imbalance, resistance development, and increased production costs. Under these circumstances, Integrated Pest Management (IPM) offers a sustainable and environmentally sound approach for managing fall armyworm. This chapter provides a comprehensive account of the biology, damage potential, and economic importance of fall armyworm, followed by detailed discussion on cultural, mechanical, biological, botanical, and chemical management strategies. Emphasis is given to ICAR-recommended practices, conservation of natural enemies, resistance management, and farmer participatory approaches for long-term suppression of fall armyworm populations under Indian agro-climatic conditions.

Keywors : Fall armyworm; *Spodoptera frugiperda*; maize; integrated pest management; biological control; insecticide resistance

1. Introduction

The fall armyworm, *Spodoptera frugiperda* (J.E. Smith), belonging to the family Noctuidae, is a highly destructive lepidopteran pest known for its wide host range and invasive potential. The insect is native to tropical and subtropical regions of the Americas, where it has long been recognized as a major pest of maize and other cereal crops (Sparks, 1979). Over the past decade, fall armyworm has gained global attention due to its unprecedented spread beyond its native range and the extensive crop losses it has caused in newly invaded regions.

The first report of fall armyworm outside the Americas came from West Africa in 2016, from where it rapidly spread across sub-Saharan Africa within a short period (Goergen et al., 2016). Subsequently, the pest invaded several Asian countries, including India, Sri Lanka, China, and Southeast Asian nations (FAO, 2019). In India, fall armyworm was first reported on maize in Karnataka during 2018, and within a few cropping seasons, it established itself across most maize-growing states of the country (Sharanabasappa et al., 2018). The rapid establishment of this pest in India is attributed to favourable climatic conditions, continuous availability of host crops, absence of diapause, and limited effectiveness of native natural enemies.

Fall armyworm is highly polyphagous and has been reported to feed on more than 80 plant species, including maize, sorghum, rice, pearl millet, sugarcane, cotton, and several vegetable crops (Montezano et al., 2018). Among these, maize is the most preferred host and suffers the highest economic damage. The larval stage is responsible for most of the damage, feeding aggressively on leaves, whorls, tassels, and cobs, resulting in significant yield losses. Characteristic symptoms such as window-pane feeding, shot-hole appearance, and accumulation of frass inside the whorl aid in field diagnosis of the pest (Kalleshwaraswamy et al., 2018).

The economic impact of fall armyworm infestation is substantial, particularly in smallholder farming systems. Yield losses in maize due to FAW infestation have been reported to range from 15 to 60 per cent, depending on crop stage and infestation intensity (Day et al., 2017). In response to severe infestations, farmers often resort to indiscriminate application of chemical insecticides, many of which provide inconsistent control due to the concealed feeding behaviour of larvae and the pest’s ability to develop resistance (Yu, 1991). Excessive use of broad-spectrum insecticides further disrupts natural enemy populations and poses risks to human health and the environment.

Given these challenges, reliance on chemical control alone is neither economically viable nor ecologically sustainable. Integrated Pest Management (IPM), which emphasizes the use of multiple compatible control tactics based on ecological principles and economic thresholds, has emerged as the most appropriate strategy for managing fall armyworm (Prasanna et al., 2018). IPM approaches aim to suppress pest populations below damaging levels while conserving natural enemies and minimizing adverse environmental effects. In the Indian context, development and adoption of IPM modules tailored to local agro-ecological conditions are critical for sustainable fall armyworm management.

This chapter synthesizes available knowledge on fall armyworm biology, ecology, and management, with a special focus on ICAR-recommended IPM practices. Emphasis is placed on integrating cultural, mechanical, biological, botanical, and chemical methods to achieve long-term and environmentally safe control of fall armyworm in maize and other crops.

2. Host Range and Nature of Damage

Fall armyworm is a highly polyphagous insect pest with an exceptionally wide host range. Globally, it has been reported to infest more than 80 plant species belonging to diverse families, particularly Poaceae, Fabaceae, and Solanaceae (Montezano et al., 2018). In India, the pest has adapted efficiently to different cropping systems and agro-ecological regions, attacking cereals, fodder crops, fibre crops, and several vegetables. Among all hosts, maize is the most preferred and economically important crop, followed by sorghum, pearl millet, finger millet, rice, sugarcane, and occasionally cotton and vegetable crops (Prasanna et al., 2018).

Damage caused by fall armyworm varies with crop stage and larval instar. In maize, infestation usually begins at the seedling stage and continues until tasseling. Early instar larvae scrape the leaf surface, feeding on the epidermal tissues and producing characteristic “window-pane” symptoms. As the larvae grow, they move into the whorl and feed on the tender, unfolding leaves. This feeding results in irregular holes and a typical “shot-hole” appearance when leaves unfurl (Kalleshwaraswamy et al., 2018).

Late instar larvae cause the most severe damage by feeding deep inside the whorl and on the growing point. Large quantities of moist frass accumulate within the whorl, which is a diagnostic feature of fall armyworm infestation. In severe cases, destruction of the growing point leads to dead heart formation, stunted plant growth, and poor cob development. When infestation occurs during the reproductive phase, larvae may feed on tassels and developing cobs, leading to poor grain filling and quality deterioration (Day et al., 2017).

In sorghum and millets, the pest causes leaf feeding and whorl damage similar to that observed in maize, whereas in rice, larvae feed on leaves and occasionally on panicles under heavy infestation. The ability of fall armyworm to shift between multiple host crops enables it to survive continuously throughout the year, particularly in regions with staggered sowing and irrigated cropping systems (FAO, 2019).

3. Economic Importance and Yield Losses

The economic significance of fall armyworm arises from its capacity to cause rapid and severe crop damage within a short period. In maize, yield losses due to fall armyworm infestation have been reported to range from 15 to 60 per cent, depending on crop growth stage, pest density, and management practices adopted (Hruska, 2019). Severe infestations during early vegetative stages can result in complete crop failure, particularly in rainfed and smallholder farming systems.

In addition to direct yield losses, fall armyworm infestation leads to increased production costs due to repeated insecticide applications. Farmers often resort to frequent spraying of broad-spectrum insecticides in an attempt to control the pest, which significantly increases the cost of cultivation and reduces net returns (Sharanabasappa et al., 2018). Such indiscriminate pesticide use also disrupts natural enemy populations and contributes to pest resurgence and secondary pest outbreaks.

From a broader perspective, fall armyworm poses a serious threat to food and nutritional security, as maize serves as a major source of food, feed, and industrial raw material in India. The pest also affects fodder crops, indirectly impacting livestock productivity. Therefore, fall armyworm infestation has both direct and indirect economic implications, emphasizing the need for sustainable and cost-effective management strategies (Prasanna et al., 2018).

4. Concept and Principles of Integrated Pest Management

Integrated Pest Management (IPM) is an ecologically based approach that aims to manage pest populations below economically damaging levels through the integration of compatible control methods. IPM does not focus on complete eradication of pests but emphasizes long-term regulation of pest populations while minimizing risks to human health and the environment (Kogan, 1998).

The fundamental principles of IPM in fall armyworm management include prevention, regular monitoring, economic threshold-based decision making, and integration of cultural, mechanical, biological, botanical, and chemical control measures. Monitoring through field scouting and pheromone traps provides early warning of pest incidence and helps in timely intervention (FAO, 2019). Application of control measures based on economic threshold levels avoids unnecessary pesticide use and reduces selection pressure for resistance.

IPM is particularly relevant for fall armyworm due to its high reproductive potential, migratory behavior, and ability to develop resistance to insecticides. Reliance on chemical control alone has proven ineffective and unsustainable in many regions, highlighting the importance of integrated approaches that conserve natural enemies and enhance ecosystem services (Yu, 1991; Kenis et al., 2019).

5. Cultural Management Practices

Cultural practices form the foundation of fall armyworm IPM and aim to reduce pest establishment, survival, and reproduction by modifying agronomic practices.

Timely and synchronized sowing

Timely sowing of maize helps the crop escape peak moth activity. Synchronised planting within a region reduces the availability of maize at different growth stages, thereby limiting continuous host availability for the pest (Prasanna et al., 2018).

Crop rotation and intercropping

Crop rotation with non-host crops such as pulses disrupts the life cycle of fall armyworm. Intercropping maize with legumes like cowpea and greengram has been reported to reduce pest incidence by increasing plant diversity and enhancing natural enemy activity (Harrison et al., 2019).

Field sanitation and tillage

Removal and destruction of crop residues after harvest eliminate leftover larvae and pupae. Deep summer ploughing exposes pupae to predators and adverse environmental conditions, thereby reducing carry-over populations (Kalleshwaraswamy et al., 2018).

Nutrient and water management

Balanced fertilization, particularly avoidance of excessive nitrogen application, reduces the susceptibility of maize plants to fall armyworm attack. Proper irrigation and maintenance of crop vigour improve the plant's tolerance to pest damage and contribute to yield stability (FAO, 2019).

Cultural practices are preventive in nature and significantly reduce the initial pest load, thereby enhancing the effectiveness of subsequent IPM interventions.

6. Mechanical and Physical Control Methods

Mechanical and physical control measures form an important supportive component of integrated fall armyworm management, particularly during the early stages of crop growth and under low to moderate infestation levels. These methods are eco-friendly, farmer-friendly, and provide immediate reduction of pest populations when applied at the appropriate time (Prasanna et al., 2018).

Hand collection and destruction

Manual collection and destruction of egg masses and early instar larvae can effectively reduce the initial pest population, especially in small fields and kitchen gardens. Egg masses of fall armyworm are usually laid on the underside of maize leaves and covered with greyish scales, making them visible during close inspection (Sharanabasappa et al., 2018). Regular field scouting and early removal of egg masses prevent larval emergence and subsequent damage.

Whorl application of inert materials

Application of inert materials such as dry sand, soil, ash, or ash mixed with lime into the maize whorl is a widely recommended indigenous practice in India. These materials cause physical injury, blockage of spiracles, and desiccation of larvae hiding deep inside the whorl (Kalleshwaraswamy et al., 2018). This method is particularly useful against medium-sized larvae that are otherwise difficult to reach with spray applications.

Light and pheromone traps

Light traps can be used at the village or community level to attract and kill adult moths, thereby reducing oviposition pressure. However, sex pheromone traps are more reliable tools for monitoring adult moth activity and population trends. Installation of pheromone traps helps in early detection of fall armyworm incidence and timely decision-making for control measures (FAO, 2019). Though pheromone traps are mainly monitoring tools, mass trapping over large contiguous areas may contribute to partial population suppression.

Mechanical and physical methods are most effective when integrated with cultural and biological approaches rather than used alone.

7. Biological Control of Fall Armyworm

Biological control is a cornerstone of sustainable fall armyworm management and plays a critical role in reducing dependence on chemical insecticides. Several natural enemies of fall armyworm have been reported from both its native and invaded regions, highlighting the potential of biological regulation under IPM programmes (Kenis et al., 2019).

7.1 Parasitoids

Egg parasitoids are among the most efficient natural enemies of fall armyworm. Species of *Trichogramma* parasitize FAW eggs and prevent larval emergence, thereby reducing crop damage at an early stage (Beserra et al., 2002). Augmentative releases of egg parasitoids at weekly intervals during peak egg-laying periods have shown encouraging results in maize ecosystems.

Larval parasitoids also contribute to population suppression by attacking early and mid-instar larvae. Parasitoids such as *Chelonus* spp. and *Campoletis* spp. reduce larval survival and feeding activity, thereby limiting crop damage (Sisay et al., 2019). Conservation of parasitoids through reduced use of broad-spectrum insecticides is essential for enhancing their effectiveness.

7.2 Predators

A wide range of generalist predators prey on fall armyworm eggs and larvae. Ants, spiders, earwigs, ladybird beetles, and predatory bugs are commonly observed in maize fields and play an important role in natural pest regulation (Harrison et al., 2019). Diversified cropping systems, reduced pesticide application, and maintenance of field vegetation help conserve predator populations.

7.3 Microbial Control Agents

Microbial control agents are environmentally safe and compatible with other IPM components.

Bacillus thuringiensis formulations have been widely used against early instar larvae of fall armyworm. These bacteria produce crystalline toxins that disrupt the larval midgut upon ingestion, resulting in mortality (Lacey et al., 2015). Timely application during early infestation stages is crucial for effective control.

Entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* infect larvae through the cuticle and cause death under favourable humidity and temperature conditions. These fungi have shown moderate to high efficacy against fall armyworm larvae and are suitable for integration into IPM programmes (Bateman et al., 2018).

Nucleopolyhedroviruses specific to fall armyworm are highly host-specific and cause epizootics under favourable conditions. Infected larvae exhibit reduced feeding and sluggish movement before death, contributing to natural population regulation (Moscardi, 1999).

8. Botanical Pesticides and Biopesticides

Botanical pesticides and biopesticides are important components of integrated fall armyworm management due to their safety, biodegradability, and compatibility with biological control agents.

Neem-based products

Neem-based formulations containing azadirachtin are widely recommended for fall armyworm management in India. These products act as antifeedants, growth regulators, and oviposition deterrents, thereby reducing larval feeding and adult egg laying (Schmutterer, 1990). Application of neem formulations during early crop stages helps suppress pest populations and delays the need for chemical insecticides.

Neem seed kernel extract has also been used as a low-cost botanical option in smallholder farming systems. Though its residual effect is short, repeated applications provide satisfactory suppression of early instar larvae (Isman, 2006).

Plant-derived extracts

Extracts from garlic, chilli, tobacco, and pongamia have shown repellent and toxic effects against fall armyworm larvae under laboratory and field conditions. These botanicals are useful as preventive measures and fit well into organic and ecological farming systems, although their effectiveness may vary with formulation and application frequency (Sisay et al., 2019).

Role in IPM

Botanicals and biopesticides are relatively safe to natural enemies and reduce the risk of pesticide residues in food and the environment. Their integration into IPM programmes contributes to resistance management and long-term sustainability of fall armyworm control (FAO, 2019).

9. Chemical Control and Resistance Management

Chemical control plays a supportive role in the integrated management of fall armyworm and should be adopted only when pest populations exceed the economic threshold level. Excessive reliance on insecticides has been identified as a major factor contributing to resistance development and environmental degradation in fall armyworm–affected regions (Yu, 1991;

Hruska, 2019). Therefore, chemical control must be judicious, need-based, and compatible with other IPM components.

In maize, insecticide application is recommended only when infestation exceeds 5–10 per cent of plants during the early vegetative stage or when two to three live larvae per plant are observed during the whorl stage (FAO, 2019). Since larvae remain concealed inside the whorl, effective spray coverage and proper timing are critical for achieving satisfactory control.

Insecticides belonging to newer chemical groups such as diamides, spinosyns, oxadiazines, and avermectins have shown better efficacy against fall armyworm when applied against early instar larvae (Prasanna et al., 2018). Targeting younger larvae not only improves control efficiency but also reduces the amount of insecticide required per application.

Resistance management is a crucial aspect of chemical control in fall armyworm. The pest has demonstrated resistance to several insecticide groups in different parts of the world due to repeated exposure and misuse (Yu, 1991). To delay resistance development, insecticides with different modes of action should be rotated, and repeated use of the same molecule should be avoided within a single cropping season. Tank mixing of insecticides without scientific justification should also be discouraged.

Integration of chemical control with biological and botanical options helps reduce selection pressure and preserves natural enemy populations. Farmers should be educated on safe pesticide use, recommended dosages, and pre-harvest intervals to minimize risks to human health and the environment.

10. Surveillance, Economic Thresholds and Farmer Participation

Effective surveillance and early warning systems are fundamental to successful fall armyworm management. Regular field scouting combined with pheromone trap monitoring provides timely information on pest incidence and population dynamics (FAO, 2019). Early detection enables farmers to implement control measures at the most vulnerable stage of the pest, thereby improving control efficiency and reducing costs.

Economic threshold levels (ETLs) form the scientific basis for decision-making under IPM. Application of control measures only when pest populations reach ETL prevents unnecessary pesticide use and promotes conservation of natural enemies (Kogan, 1998). Adoption of ETL-based interventions has been shown to significantly reduce pesticide input without compromising yield.

Farmer participation is critical for effective fall armyworm management, particularly because of the pest's migratory nature. Community-based approaches such as synchronized sowing, coordinated monitoring, and collective implementation of control measures are more effective than isolated efforts by individual farmers (Prasanna et al., 2018). Farmer Field Schools and extension programs play a key role in building awareness, enhancing diagnostic skills, and promoting IPM adoption.

11. Challenges in Fall Armyworm Management

Despite the availability of several management options, fall armyworm control faces multiple challenges. The pest's high reproductive potential, overlapping generations, and strong migratory ability complicate timely management. Climatic variability and continuous host availability further favour pest persistence (Day et al., 2017).

Limited availability of quality biopesticides, lack of awareness among farmers, and overdependence on chemical insecticides remain major constraints in many regions. In addition, resistance development and negative impacts of pesticides on natural enemies pose serious threats to the sustainability of FAW management programs (Kenis et al., 2019).

Addressing these challenges requires strengthening research–extension linkages, improving access to IPM inputs, and promoting region-specific management strategies.

12. Future Strategies and Research Needs

Future fall armyworm management strategies should focus on strengthening preventive and ecological approaches. Development of pest-resistant maize varieties, enhancement of biological control through conservation and augmentation, and refinement of microbial and botanical formulations are important research priorities.

Use of digital tools such as remote sensing, mobile-based advisory services, and decision-support systems can improve surveillance and timely intervention. Long-term success in fall armyworm management will depend on integrating scientific innovations with farmer participation and policy support.

13. Conclusion

Fall armyworm has emerged as a major constraint to maize and allied crop production in India and other parts of the world. Its invasive nature, wide host range, and adaptability necessitate a holistic and sustainable management approach. Integrated Pest Management provides an effective framework for fall armyworm control by combining cultural, mechanical, biological, botanical, and chemical methods based on ecological principles and economic thresholds. Adoption of ICAR-recommended IPM practices, conservation of natural enemies, rational use of insecticides, and active farmer participation are essential for achieving long-term suppression of fall armyworm populations. Sustainable management of this pest is critical for safeguarding crop productivity, environmental health, and food security.

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THE MICROBIAL SHIELD HARNESSING PLANT–MICROBIOME INTERACTIONS FOR PEST RESILIENCE

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Introduction

Crop losses due to insect pests, nematodes, and pathogenic organisms continue to pose a major challenge to global food security. Conventional pest management strategies rely heavily on synthetic pesticides, which have led to ecological imbalance, pesticide resistance, resurgence of secondary pests, and adverse effects on non-target organisms and human health. In this context, sustainable and biologically driven alternatives are urgently required. Recent advances in plant–microbe interactions have revealed that plants do not function as isolated organisms but rather as complex biological systems intricately associated with diverse microbial communities, collectively referred to as the plant microbiome.

The plant microbiome includes bacteria, fungi, archaea, viruses, and protists colonizing the rhizosphere, phyllosphere, endosphere, and surrounding soil. These microbial assemblages play a pivotal role in nutrient acquisition, stress tolerance, growth promotion, and defense against pests and pathogens. The concept of the "microbial shield" has emerged to describe the collective protective functions provided by plant-associated microbiomes that enhance pest resilience and reduce pest pressure. This microbial shield operates through multiple mechanisms, including direct antagonism of pests, induction of plant defense responses, modulation of plant secondary metabolites, and enhancement of biological control.

Understanding and harnessing the microbial shield offers a promising pathway toward eco-friendly pest management and resilient agroecosystems. This chapter explores the structure, mechanisms, assembly, and application of plant microbiomes as a microbial shield for pest resilience, with emphasis on translational strategies for sustainable agriculture.

Concept of the Microbial Shield

The microbial shield refers to the protective barrier formed by beneficial microorganisms associated with plants that collectively suppress pest establishment, survival, and reproduction. Unlike single biocontrol agents, the microbial shield is an emergent property of microbial communities and their interactions with the host plant and environment. It functions at multiple spatial levels, including the **rhizosphere**, **phyllosphere**, **endosphere**, and **bulk soil**, each contributing uniquely to pest resistance.

In the rhizosphere, root-associated microbes influence root exudation patterns, nutrient availability, and systemic signaling pathways that affect above-ground pest interactions. Endophytic microbes residing within plant tissues enhance internal defense mechanisms and produce bioactive metabolites that deter herbivores. Phyllosphere microbes colonizing leaf surfaces can directly inhibit insect feeding or interfere with oviposition behavior. At the soil level, complex microbial networks suppress soil-borne pests and disrupt pest life cycles.

The effectiveness of the microbial shield depends on microbial diversity, functional redundancy, host genotype compatibility, and environmental conditions. A stable and diverse microbiome ensures resilience against disturbances and maintains consistent protective functions. Thus, the microbial shield represents a holistic and dynamic defense system rather than a single microbial solution.

Mechanisms of Microbiome-Mediated Pest ResilienceDirect Antagonism of Pests

One of the primary mechanisms by which the microbial shield operates is through direct antagonism of pests. Several plant-associated microorganisms produce antibiotics, lytic enzymes, toxins, and secondary metabolites that directly suppress insect pests, nematodes, and pathogenic fungi. For example, species of *Bacillus* and *Pseudomonas* produce lipopeptides, phenazines, and hydrogen cyanide that exhibit insecticidal and nematicidal properties.

Entomopathogenic and nematophagous fungi such as *Beauveria bassiana*, *Metarhizium anisopliae*, and *Arthrobotrys* spp. infect, trap, or kill insect larvae and nematodes in the soil. These organisms not only reduce pest populations but also persist in the soil ecosystem, contributing to long-term suppression. Competition for space and nutrients further limits pest colonization, particularly in the rhizosphere where beneficial microbes occupy ecological niches that pests would otherwise exploit.

Induced Systemic Resistance (ISR)

Microbial-mediated induced systemic resistance (ISR) is a key indirect mechanism of pest suppression. Certain rhizobacteria and endophytes prime plant defense pathways without causing disease, enabling plants to respond more rapidly and effectively upon pest attack. ISR is primarily regulated through jasmonic acid (JA) and ethylene (ET) signaling pathways, which are crucial for defense against herbivorous insects.

Microbes such as *Pseudomonas fluorescens* and *Bacillus subtilis* trigger ISR, leading to increased production of defensive enzymes, proteinase inhibitors, phenolic compounds, and lignin. This primed state does not impose a significant metabolic cost on plants under non-stress conditions but confers enhanced resistance when pests attack. ISR has been shown to reduce larval feeding, slow pest development, and lower pest fecundity across various crop systems.

Modulation of Plant Secondary Metabolites

Plant secondary metabolites play a central role in plant defense against pests. The plant microbiome can significantly influence the biosynthesis and accumulation of these compounds. Microbial interactions alter plant metabolic pathways, leading to increased production of alkaloids, terpenoids, flavonoids, and glucosinolates that deter herbivores.

For instance, endophytic fungi have been shown to enhance alkaloid content in grasses, thereby reducing insect herbivory. Similarly, rhizosphere microbes can influence phenolic metabolism, strengthening plant cell walls and reducing palatability. These biochemical changes collectively contribute to the microbial shield by making plants less attractive or less nutritious to pests.

Indirect Ecological Effects and Biological Control

Beyond direct and plant-mediated mechanisms, the microbial shield also functions through indirect ecological interactions. Microbe-induced changes in plant volatile organic compounds (VOCs) can attract natural enemies such as parasitoids and predators, enhancing biological control. These microbe-induced plant volatiles (MIPVs) act as signals that guide beneficial insects to pest-infested plants.

Additionally, microbial modulation of plant nutritional status influences pest performance. Reduced foliar nitrogen content or altered carbon–nitrogen ratios can negatively affect herbivore growth and reproduction. Some microbes also disrupt pest-associated symbionts, which are essential for pest digestion and detoxification, thereby indirectly reducing pest fitness

Assembly and Stability of Protective Microbiomes

The formation of an effective microbial shield depends on the assembly and stability of plant-associated microbial communities. Host plant genotype plays a critical role in shaping microbiome composition through root exudates, surface chemistry, and immune responses. Soil type, cropping history, organic amendments, and tillage practices influence the pool of microbes available for colonization.

Environmental factors such as temperature, moisture, and pH act as ecological filters, determining microbial survival and activity. Priority effects—where early colonizing microbes influence subsequent community composition—are particularly important during seed germination and early plant growth. Functional redundancy within microbial communities enhances stability, ensuring that protective functions persist even if individual taxa decline.

Disturbances such as excessive fertilizer use, broad-spectrum pesticides, and monocropping can disrupt microbial networks and weaken the microbial shield. Therefore, sustainable management practices are essential for maintaining a resilient and protective plant microbiome.

Strategies to Harness the Microbial Shield in Agriculture

Microbial Inoculants and Synthetic Communities

The application of beneficial microbial inoculants is a practical approach to enhancing the microbial shield. Single-strain biocontrol agents have been widely used; however, their performance often varies across environments. Recently, synthetic microbial communities (SynComs) composed of multiple functionally complementary strains have gained attention for their improved consistency and resilience.

Successful inoculation depends on strain compatibility, formulation quality, carrier materials, shelf life, and application method. Seed coating, soil drenching, nursery treatments, and foliar sprays are commonly employed to establish beneficial microbes at critical growth stages

Host Plant Breeding for Microbiome Recruitment

Plant breeding programs are increasingly recognizing the importance of microbiome recruitment traits. Selecting crop genotypes that favor beneficial microbial colonization offers a long-term strategy for strengthening the microbial shield. Advances in genomics and quantitative trait locus (QTL) mapping have identified plant genes involved in microbiome assembly, opening avenues for microbiome-assisted breeding

Agronomic and Soil Management Practices

Agronomic practices significantly influence the effectiveness of the microbial shield. Organic amendments, cover cropping, crop rotation, reduced tillage, and diversified cropping systems enhance microbial diversity and activity. These practices create favorable conditions for beneficial microbes and suppress pest outbreaks naturally.

Integration with Integrated Pest Management (IPM)

The microbial shield should be integrated into broader Integrated Pest Management (IPM) frameworks. Combining microbial strategies with host resistance, biological control, and judicious pesticide use enhances overall pest suppression while minimizing environmental impacts. Compatibility testing is essential to ensure that microbial agents are not adversely affected by chemical inputs.

Constraints and Future Prospects

Despite its promise, microbial shield deployment faces challenges including context-dependent efficacy, variability under field conditions, regulatory hurdles, and limited farmer awareness. Non-target effects and ecological risks must be carefully assessed. Future research should focus on long-term field studies, mechanistic understanding, community-level engineering, and development of region-specific microbial solutions.

Conclusion

The microbial shield represents a paradigm shift in pest management, emphasizing ecological processes and plant–microbe partnerships rather than chemical control. By harnessing the multifunctional roles of plant-associated microbiomes, agriculture can achieve enhanced pest resilience, reduced pesticide dependence, and improved sustainability. Strategic integration of microbial inoculants, host breeding, and soil health management will be key to realizing the full potential of the microbial shield in future agroecosystems

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BIOACOUSTIC SURVEILLANCE SYSTEMS FOR DETECTING INSECTS FOR SUSTAINABLE AGRICULTURE

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Introduction

Sustainable agriculture increasingly relies on precise, environmentally benign technologies to manage insect pests while minimizing chemical inputs. Conventional pest surveillance methods—visual scouting, pheromone trapping, and destructive sampling—are labor-intensive, intermittent, and often ineffective for detecting early infestations, particularly when insects are concealed within plant tissues, soil, or stored commodities. Bioacoustic surveillance systems offer a non-invasive alternative by detecting and interpreting sounds and vibrations produced by insects during flight, feeding, mating, and movement. By “listening” to insect activity, these systems provide continuous, real-time insights into pest presence and behavior, supporting timely and targeted interventions within integrated pest management (IPM) frameworks.

Principles of Insect Bioacoustics

Insects produce species- and behavior-specific acoustic signatures through diverse mechanisms. Flying insects generate characteristic wing-beat frequencies and harmonics, while many beetles and orthopterans produce sounds through stridulation or percussion. Larval stages of stored-product pests and stem borers generate substrate-borne vibrations during feeding and movement. These signals vary in frequency (from a few tens of Hz to several kHz), temporal structure, and amplitude, depending on species, life stage, and environmental context.

Sound propagation differs markedly between airborne and substrate-borne pathways. Airborne signals attenuate rapidly in open fields due to wind and vegetation, whereas vibrations transmitted through grain, soil, or plant tissues can travel farther with less loss. Understanding these biological and physical principles is crucial for selecting appropriate sensors and optimizing their placement in agricultural settings.

Components of Bioacoustic Surveillance Systems

A typical bioacoustic surveillance system consists of sensors, data acquisition units, signal-processing modules, and decision-support interfaces.

Sensors:

Airborne microphones (electret or MEMS-based) are used to capture wing-beat sounds and calls of flying insects. Contact sensors, such as piezoelectric transducers and accelerometers, are employed to detect vibrations produced by concealed insects in grain bulks, tree trunks, or plant stems. Sensor choice depends on the target pest and its acoustic behavior.

Data acquisition and transmission:

Low-power microcontrollers digitize acoustic signals, often performing preliminary filtering and compression. In modern deployments, sensors are integrated into Internet of Things (IoT) networks, enabling wireless data transmission to local gateways or cloud platforms for analysis.

Power and housing:

Solar panels and long-life batteries support continuous operation in remote fields. Weatherproof enclosures protect sensors from dust, moisture, and temperature extremes, ensuring durability under farm conditions.

Signal Processing and Feature Extraction

Raw acoustic data contain substantial background noise from wind, rain, machinery, and other organisms. Signal processing begins with noise reduction and band-pass filtering to isolate frequency ranges relevant to target insects. Time–frequency analyses, such as short-time Fourier transforms, convert signals into spectrograms that visually and computationally represent acoustic patterns.

Key features extracted from these signals include wing-beat frequency, harmonic structure, pulse repetition rate, energy distribution, and temporal variability. For substrate vibrations, impulse counts and inter-pulse intervals are particularly informative. These features form the basis for automated detection and classification.

Machine Learning and Automated Identification

Advances in machine learning have transformed bioacoustic surveillance from manual listening to automated, scalable monitoring. Classical algorithms—such as support vector machines and random forests—use engineered features to discriminate between pest and non-pest sounds. More recently, deep learning approaches, especially convolutional neural networks trained on spectrogram images, have achieved higher accuracy in species identification and activity detection.

Automated systems can operate in near real time, flagging pest presence when acoustic activity exceeds predefined thresholds. Integration of edge computing allows preliminary classification directly on the sensor node, reducing data transmission requirements and enabling rapid alerts.

Applications in Sustainable Agriculture

Field crop monitoring:

In open-field crops, bioacoustic sensors can monitor populations of flying pests and beneficial insects, providing insights into pest pressure and pollinator activity. Continuous acoustic data help identify peak activity periods, improving the timing of interventions.

Stored-product protection:

One of the most successful applications of bioacoustics is in stored grain and processed commodities. Contact sensors inserted into grain bulks detect larval feeding sounds long before infestations become visible, allowing early management and reducing post-harvest losses without excessive fumigation.

Orchards and forestry systems:

Vibration sensors attached to tree trunks can detect wood-boring insects at early stages, supporting targeted treatments and preventing structural damage to perennial crops.

Emerging UAV-based surveillance:

Unmanned aerial vehicles equipped with lightweight microphones are being explored for rapid, large-area acoustic surveys. Although challenges such as drone noise remain, this approach holds promise for scouting inaccessible or extensive fields.

Integration with Integrated Pest Management

Bioacoustic surveillance aligns closely with IPM principles by emphasizing prevention, monitoring, and precision intervention. Acoustic alerts can trigger targeted scouting, biological control releases, or localized pesticide applications, reducing overall chemical use. When combined with weather data, crop phenology, and decision-support models, bioacoustics enhances the predictive capacity of pest management systems.

Challenges and Limitations

Despite its promise, bioacoustic surveillance faces several challenges. Environmental noise can cause false detections, necessitating robust algorithms and careful sensor placement. Limited labeled datasets for many pest species constrain machine-learning performance. Detection range is often short in open environments, requiring dense sensor networks. Additionally, costs, maintenance requirements, and technical expertise may limit adoption by smallholder farmers unless simplified, low-cost solutions are developed.

Future Prospects

Future research is expected to focus on standardized acoustic libraries for major pests, improved noise-robust algorithms, and multimodal sensing that combines acoustics with imaging, pheromone traps, and environmental sensors. Advances in edge AI and low-power electronics will further enable autonomous, farm-scale deployments. As these systems mature, bioacoustic surveillance is likely to become a core component of digital and sustainable agriculture.

Conclusion

Bioacoustic surveillance systems represent a transformative approach to insect detection in sustainable agriculture. By enabling non-invasive, continuous, and early monitoring of pest activity, they support precise and environmentally responsible pest management. Continued interdisciplinary collaboration among entomologists, engineers, and agronomists will be essential to overcome current limitations and fully realize the potential of listening-based technologies in agroecosystems.

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ROLE OF CROP DIVERSIFICATION IN REDUCING PEST OUTBREAKS IN CEREAL-BASED CROPPING SYSTEMS

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Introduction

Cereal-based cropping systems such as rice–wheat, maize–wheat, sorghum–millet, and rice–rice dominate large agricultural regions due to their high productivity and food security importance. However, long-term dependence on monoculture or limited crop rotation has resulted in frequent and severe pest outbreaks. Uniform host availability, synchronized crop phenology, and reduced biodiversity create ideal conditions for rapid pest multiplication. Crop diversification has emerged as a sustainable ecological strategy to suppress pest populations by disrupting pest life cycles, enhancing natural enemy activity, and improving overall agroecosystem resilience.

Concept of Crop Diversification

Crop diversification refers to the practice of growing a variety of crops in space and/or time within a farming system. In cereal-based systems, diversification may include crop rotation, intercropping, mixed cropping, relay cropping, cover cropping, and inclusion of legumes, oilseeds, vegetables, or fodder crops alongside cereals. Unlike monocropping, diversified systems increase plant species richness and structural complexity, which directly and indirectly influence pest dynamics.

Mechanisms by Which Crop Diversification Reduces Pest Outbreaks

a) Disruption of Pest Host Continuity

Most insect pests are host-specific and depend on continuous availability of a particular crop. Continuous cereal cultivation allows pests such as stem borers, planthoppers, aphids, and armyworms to survive and multiply across seasons. Crop diversification breaks this continuity by introducing non-host crops, thereby interrupting pest life cycles. Rotation of cereals with legumes or oilseeds reduces carryover populations of pests and minimizes the buildup of pest inoculum in the field.

b) Reduced Pest Colonization and Spread

In diversified systems, pests face difficulty in locating their preferred host plants due to visual and chemical interference from non-host crops. The presence of multiple crop species masks host plant cues, reducing pest landing, feeding, and oviposition. Intercropping cereals with legumes or aromatic plants alters the microenvironment and makes pest colonization less efficient compared to uniform cereal monocultures.

c) Enhancement of Natural Enemies

Crop diversification increases habitat heterogeneity and provides food resources such as nectar, pollen, and alternate prey for beneficial organisms including predators and parasitism. Flowering intercrops and border crops support natural enemies like ladybird beetles, lacewings, spiders, and parasitic wasps. Enhanced biological control leads to natural regulation of pest populations and reduces dependence on chemical pesticides.

d) Alteration of Microclimate

Diversified cropping systems modify field microclimate by changing light penetration, temperature, humidity, and wind flow. Many cereal pests thrive under specific microclimatic conditions. Intercropping and mixed cropping can create less favourable environments for pest development, survival, and reproduction. For example, reduced canopy temperature and altered humidity may suppress pest egg hatch and larval survival.

e) Trap and Repellent Effects

Certain crops act as trap crops by attracting pests away from the main cereal crop, while others function as repellent crops that deter pest entry. Diversified systems strategically exploit pest behavior by manipulating host preference. Push–pull systems in cereals, where repellent intercrops push pests away and attractive border crops pull them away from the main crop, are effective examples of ecological pest management.

Role of Legumes in Cereal Diversification

Legumes play a key role in cereal-based diversification strategies. Apart from improving soil fertility through biological nitrogen fixation, legumes reduce pest incidence by acting as non-host crops. Intercropping cereals with pulses reduces populations of cereal-specific pests and supports beneficial insects. Improved crop vigor resulting from better soil health also enhances the cereal crop's tolerance to pest damage.

Impact on Pest Population Dynamics

Diversified systems generally show lower pest density, reduced pest damage, and slower pest population growth rates. Pest outbreaks, which are common in monoculture systems due to synchronized crop stages and uniform host availability, are less frequent and less severe under diversified cropping. Pest resurgence following pesticide application is also minimized because natural enemy populations are better conserved.

Integration with Integrated Pest Management (IPM)

Crop diversification is a core component of Integrated Pest Management. It complements other IPM practices such as resistant varieties, biological control, mechanical methods, and judicious pesticide use. By reducing initial pest pressure, diversification lowers the need for chemical interventions, making pest management more cost-effective, environmentally friendly, and sustainable.

Socio-Economic and Environmental Benefits

Beyond pest suppression, crop diversification improves farm income stability by reducing risk, enhancing yield stability, and providing multiple products. Reduced pesticide use lowers production costs and minimizes environmental pollution. Diversified cereal systems also contribute to biodiversity conservation, soil health improvement, and climate resilience, making them suitable for sustainable agriculture under changing climatic conditions.

Conclusion

Crop diversification plays a crucial role in reducing pest outbreaks in cereal-based cropping systems by disrupting pest life cycles, suppressing pest colonization, enhancing natural enemies, and stabilizing agroecosystems. Diversified systems offer an ecologically sound and economically viable alternative to pesticide-dependent monocropping. Adoption of crop diversification strategies

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Colletotrichum capsici AN OVERVIEW IN TURMERIC LEAF SPOT

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Turmeric (*Curcuma longa* L.) is one of the most significant old sacred rhizomatous species in India, is a member of the Zingiberaceae family and is grown there for industrial, culinary, medicinal and religious uses. The sociocultural life of the Indian subcontinents inhabitants is closely linked to turmeric. The inhabitants of the vedic era considered this " earthy herb of the Sun" with the orange-yellow rhizome to be the " herb of the Sun". It makes sense that the ancient people considered turmeric to be the " Oushadhi" , the medicinal herb, the most exceptional herb, and superior to all other herbs. When it comes to production, consumption and export of turmeric, India leads the world. In 2021-2022, its total production was 1334 thousand MT with an 349 thousand hectares in size (Agricultural Statistics at a Glance, 2022). Telangana, Andhra Pradesh, Tamil Nadu, Karnataka, Orissa, West Bengal and Maharashtra are the main Indian states that produce turmeric. In Uttar Pradesh 1.76 thousand hectares and 3.64 MT of turmeric were produced in 2021 and 2022, respectively. Because of its extreme susceptibility to a number of fungal diseases, including leaf spot, leaf blotch, rhizome rot etc., its quantitative and quantitative production drastically declines.

Leaf spot is the most significant of these illnesses, causing yield losses of up to 62.12 per cent in several of India's key turmeric-growing districts (Jagtap et al. 2013) . McRac was the first person from the Coimbatore district to report the illness in Tamil Nadu during 1917. In all of India's turmeric- growing regions, the illness is now more common and damaging. August and September are when the disease typically first appears in the field, and November and December, when the average temperature is between 20 and 25 ^{o} C and the atmosphere has a high relative humidity, are when it becomes more aggressive. Because of the high and continuous humidity in the air, the illness usually appears between August and Septe mber. It was also observed in October and November.

Symptoms

Typically, the pathogen attacks leaves. Although it can occasionally spread to the leaf sheaths, the disease mainly affects leaf blades.

The main sign of the condition is elliptic or oblong patches of varying sizes. They are little at first, with dimensions of 1.0 to 1.5 inches in breadth and 1.5 to 2.0 inches in length. But many of them enlarge rapidly. When two or more of these spots come together, they often form uneven patches that cover a large portion of the leaf before drying out. Every place has a unique look. On both surfaces the core is thin, grayish white, and covered in a large number of black acervuli-like spots arranged in concentric rings (Kumawat *et al*., 2022). A brown border encircles the area of spots outside of the portion that is grayish white. The area outside is surrounded by a light yellowish aura. The marks are more noticeable on the upper surface of fresh leaves, even though they are visible on both surfaces. When disease frequency is significant, the majority of the leaves dry up and the field seems parched. *Colletotrichum capsici* causes the devastating Turmeric Leaf Spot disease, a major fungal threat leading to significant yield and quality loss in turmeric (*Curcuma longa*) globally, sometimes up to 62%, affecting both quantity and quality of turmeric rhizomes, especially in major growing regions like India and Ethiopia, characterized by distinctive gray-white spots with black dots (fruiting bodies - acervuli) on leaves that scorch.

Pathogen Characteristics

The conidia (spores) are typically single-celled, hyaline (clear), and distinctly sickle-shaped or crescent-shaped. The fungus produces cottony colonies with varying colours (white, black, pinkish) in concentric ring patterns when cultured in a lab. It has a broad host range, including chili peppers, yams, and bitter gourd, but is particularly virulent on turmeric isolates.

Conditions for Development

The disease is more severe during the rainy season and under high humidity conditions, with optimal fungal growth observed around 30°C and pH 6.5. High relative humidity and specific temperature ranges influence disease severity.

Management Strategies

Turmeric leaf spot disease incited by *C. capsici* management involves cultural, biological, and chemical methods by using fungicides, botanicals, and biocontrol agents like *Trichoderma*. Monoculture practices can exacerbate epidemics, highlighting the need for integrated management.

Cultural Practices:

- Ensuring proper field sanitation and drainage.
- Using resistant or tolerant varieties where available
- Crop rotation.

Biological Control:

Bio-control agents such as *Trichoderma harzianum* and *Pseudomonas fluorescens* have shown effectiveness in inhibiting fungal growth.

Botanicals:

Plant extracts, especially from garlic leaf and cloves and iron weed, have demonstrated significant antifungal properties against the pathogen. NSKE 5 % extract also effective.

Chemical Control:

- Foliar sprays of fungicides are a common and effective control measure.
- Systemic fungicides like **propiconazole**, **hexaconazole**, **azoxystrobin,** and **carbendazim** provide excellent control, often showing 100% inhibition in lab tests.
- Non-systemic (contact) fungicides such as **mancozeb** and copper oxychloride are also effective.
- A combination of carbendazim and mancozeb has been found to be very effective.

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RICE FALSE SMUT INCITANT *Ustilaginoidea virens*: MANAGEMENT STRATEGIES

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Rice (*Oryza sativa* L.) is one of the most significant and wellknown cereal crops in the world, in a member of the Poaceae family. Two cultivated species such as *Oryza sativa* and *O. glaberrima*, plus twenty wild species make up rice.In some nations where rice is the primary staple food, 20 % of the protein in the diet comes from rice (FAO, 2004). In addition to having a high carbohydrate content, rice also contains trace amounts of fat, protein and vitamin B compl exes like thiamine, riboflavin, and niacin. Minerals like calcium (Ca), magnesium (Mg) and phosphorus (P) are abundant in rice grains. Oryzanol, β-sitosterol, lignin, pectin, arabinoxylan are phytochemical molecules found in rice bran that may have anti-disease capabilities and essential amino acids such as arginine, cysteine, histidine and tryptophan also present.

A total of 782 MT of rice are produced worldwide on 167 million hectares of land (FAOS TAT, 2018). India is the second- largest producer of rice after China with 109.70 MT produced on 43.99 million hectares of land with a productivity of 2494 kg/ha (Anonymous 2016. Numerous biotic and abiotic factors have an impact on rice productivity. In many nations, the use of fertilizers, pesticides, and high- yielding cultivars in rice cultivation has led to the occurrence and severity of biotic stresses. False smut, a fungal disease produced by *U. virens* (Cooke), significantly reduces the yield of rice grains. Velvety yellow to green balls that eventually turn black are the disease's hallmark also called as false smut balls . Favourable weather conditions cause severe damage when the rice canopy is most dense, resulting in the infection of rice flower and ultimately protrude out of the spikelets to form false smut balls.

The fungal disease known as false smut in rice, caused by *Ustilaginoidea virens* and also referred to as *Villosiclava virens* in its perfect state, was initially identified in 1878 by Cooke in the Tirunelveli district of Tamil Nadu, India. This condition, also called Green smut or Lakshmi disease, has since been observed in numerous countries, encompassing nearly all rice-producing areas worldwide, such as the Philippines, Myanmar, Colombia, Peru, Bangladesh, Mauritius, Nigeria, Sri Lanka, Fiji, and various regions in Africa. Following the initial discovery in Tamil Nadu, India (Cooke, 1878), outbreaks of false smut have been documented in other Indian states, including Haryana, Punjab, Uttar Pradesh, Uttarakhand, Karnataka, Andhra Pradesh, Bihar, Jharkhand, Gujarat, Maharashtra, Jammu and Kashmir, and Pondicherry.

Symptoms

The pathogen impacts rice plants during the flowering phase, leading to the formation of false smut balls (Fig 1). Numerous researchers from various parts of the globe have documented the disease's symptoms. When the climate is favourable, the pathogen infects the rice plant during panicle development, invading the inner parts of rice flowers with mycelia. The young ovary of a single spikelet is transformed into large, velvety balls that range in colour from yellow to green. According to researchers, these smut balls not only obstruct the milking of rice grains but also increase spikelet sterility and ball formation, leading to reduced yield. These smut balls are more than twice the diameter of normal grains, initially appearing yellow before turning dark green or nearly black.

Initially, the infection starts on a few grains and eventually spreads to the entire panicle, with the potential to reach 100% infection in cases of severe disease outbreaks. It has also been documented that the pathogen responsible for this condition produces significant quantities of mycotoxins, including Ustiloxins and Ustilaginoidins. These toxins exhibit phytotoxic properties, inhibiting the growth of shoots and roots in germinating rice seeds. Additionally, the Ustilaginoidins possess antibacterial properties against both plant and human pathogens.

Integrated disease management

One of the most effective and cost-efficient strategies for managing plant diseases is the use of resistant plant varieties. These varieties are developed by identifying resistance genes that can combat the current virulent strains of the fungus. While chemical treatments can control pathogens, prolonged use of fungicides has led to resistance in the pathogens and negatively impacts the ecosystem. Using resistant cultivars is a promising and preferred method for disease management, but it has its limitations. The main issue is the reduced effectiveness of qualitative resistance genes when exposed to field conditions. However, resistance can be more durable if it is governed by polygenes and supplemented with other disease control measures. Therefore, integrated disease management emerges as the most economical and effective approach to disease control.

False smut of rice and crop yield loss can be minimized through adapting certain cultural practices, biological control, host resistance, nutrition, bio-pesticides and use of chemical fungicides.

Cultural control

- Deep summer ploughing helps to reduce sclerotia.
- Destruction of infected straw/stubble; cleaning of field bunds and canals to remove grass weeds.
- Use certified disease-free seeds
- Adopt early sowing for lesser disease incidence
- Avoid close transplanting and enormous irrigation that increase the incidence of rice false smut with high humidity.
- Avoid the repeated cultivation of rice in previous year infected area.
- Follow furrow irrigation in rice cultivation system to reduce false smut disease severity that reduces the survival period of chlamydospores in soil.

Biological control

- Eco-friendly management of plant diseases include biological control with the use of *Trichoderma* isolates *viz., T. viride*, *T. virens*, *T. harzianum* and *T. reesei* isolated from the rhizosphere of rice crop have antagonistic properties against the false smut pathogen.
- Combined application of *Bacillus subtilis* (BS-916) and validamycin 2.5% against the *Ustilaginoidea*, provide more than 90% reduction in disease with one spray at the late booting stage of rice crop.
- Plant extracts *viz.,* bulb extract of garlic (*Allium sativum*), bael (*Aeglemarmelos*), leaf extract of lantana (*Lantana camara*), extract of turmeric (*Curcuma longa),* Lemon grass (*Cymbopogan flexuous*), cinnamon (*Cinnamomum zeylanicum*) and palmarosa (*Cymbopogan martini*) inhibited the growth of *U. virens* pathogen.

Nutrition

- Type of fertilizers, dosage and time of application have significant effect on incidence and severity of the rice false smut.
- Nitrogen fertilizers applied late in the season showed high incidence of disease with increased number of balls/plant.

Chemical control

Apply fungicides at the boot leaf stage and 50% flowering for best results.

- Copper oxychloride and copper hydroxide are highly effective in managing the disease.
- Application of propiconazole 25EC (0.1%) and copper oxychloride 50WP (0.3%) are found most effective.
- Combination of azoxystrobin and difenconazole spray reduced disease at the maximum of 94 %.
- Propiconazole and hexaconazole (0.1%) treatment resulted in lowest disease severity than other fungicides applied at 50% panicle emergence.

Combination of these methods focusing on preventing primary infection and managing the plant during sensitive stages like flowering.

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DIGITAL AND PARTICIPATORY EXTENSION TOOLS FOR INSECT PEST SURVEILLANCE, FORECASTING, AND ADVISORY SYSTEMS

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ABSTRACT

Insect pest surveillance systems were historically expert-centric, intermittent, and spatially limited, leading to delayed outbreak recognition and generalized extension advisories. The integration of digital agriculture and participatory extension transformed surveillance into a real-time, farmer-linked intelligence ecosystem. This chapter examined mobile-enabled pest reporting platforms, AI-based insect recognition, IoT-powered smart traps, micro-climate sensors, and GIS-linked hotspot mapping, combined with participatory models such as community pest scouts and Farmer Field Schools. The convergence enhanced outbreak forecasting through localized climate-pest correlations and enabled rapid advisory dissemination via SMS, IVR, apps, and social networks in local languages. The chapter highlighted that trust-based validation loops and surveillance literacy training were key to improving advisory adoption and reducing panic pesticide spraying. It concluded that digitally networked and socially embedded extension entomology systems strengthened early warning, collective response, and ecological compliance, forming a scalable pathway for sustainable, data-driven pest advisory services.

Keywords: Digital Pest Surveillance, Participatory Extension, AI-Based Insect Advisory

1. Introduction

Insect pest outbreaks historically posed not only biophysical damage to crops but also systemic challenges to rural advisory mechanisms. Pest infestations spread faster than extension advisories, creating a chronic mismatch between insect population dynamics and information delivery cycles. Earlier systems depended on periodic field diagnostics by entomologists or extension officers, but the limited number of experts, large jurisdictional areas, and slow data recording mechanisms delayed outbreak recognition. Consequently, advisories were generic rather than localized, reactive instead of predictive, and individually interpreted rather than socially coordinated. The digital transformation of Indian agriculture, supported by increasing rural internet penetration and ICT-enabled extension reforms, shifted pest monitoring into a real-time, data-rich, community-linked decision ecosystem. Surveillance was no longer a unidirectional process; it evolved into a co-generated intelligence system where farmers, extension workers, youth pest scouts, and automated monitoring devices contributed data that fed forecasting engines and advisory triggers. This convergence strengthened extension entomology by embedding insect ecology within communication sciences, human behaviour, risk psychology, and participatory decision pathways.

2. Conceptual Foundation: Surveillance as a Socio-Digital Knowledge Network

The new surveillance architecture was anchored in both entomological science and extension communication frameworks. Digital entomology contributed pest life stage recognition, population thresholds, phenology modelling, and environmental response variables. Agricultural extension contributed the social scaffolding—farmer networks, advisory translation, behaviour change messaging, training modules, trust validation loops, and institutional coordination. The integration of these disciplines converted surveillance into a hybrid model combining crowdsourced field observations, AI-enabled insect recognition, IoT micro-climate sensing, and multi-channel advisory delivery. The chapter treated pest surveillance as a knowledge network rather than a monitoring checklist, emphasizing that outbreak responsiveness depended on data frequency, spatial granularity, communication velocity, and community compliance synchronization.

3. Mobile-Enabled Participatory Pest Reporting and Expert Validation

Mobile pest reporting platforms transformed extension workers and farmers into continuous data contributors. Farmers captured pest symptoms such as egg masses, larval clusters, frass deposition, exit holes, honeydew secretion, and early wilting patterns using smartphones. Unlike earlier paper-based records, these digital reports carried GPS coordinates, time stamps, crop stage information, and visual proof. AI insect recognition engines processed these images using deep learning classifiers trained on large morphological datasets. However, adoption studies indicated that farmers trusted AI outputs only when they were verified by human experts.

Extension systems therefore institutionalized digital validation loops, where entomologists or trained extension diagnosticians confirmed or corrected AI outputs and posted responses back to farmers via app dashboards or messaging groups. This iterative validation process not only improved diagnostic accuracy but also built farmer confidence in digital surveillance, reducing misinformation and panic responses. In rural areas where typing literacy was low, farmers increasingly preferred voice-based symptom narration. Many platforms integrated speech-to-text and voice advisory modules, enabling richer field descriptions, particularly for nocturnal insect activity or hidden pest symptoms that were hard to visually photograph. These systems collectively reduced surveillance latency and strengthened extension responsiveness.

4. Smart Traps, Automated Counting, and Temporal Pest Curves

AI-enabled smart traps introduced continuous insect population monitoring at scale. Traditional pheromone or light traps depended on manual checking, but smart traps embedded machine vision cameras, infrared counters, or optical sensors powered by solar units. These traps automatically counted insects, plotted species-specific population curves, and uploaded data to cloud dashboards accessible by extension officers. The continuous nature of these traps revealed pest pressure fluctuations that earlier systems could not detect, particularly the night-time breeding and movement bursts of pests like fall armyworm, stem borers, whiteflies, and fruit flies. Entomological research demonstrated that many pests responded to micro-climatic triggers—especially leaf wetness duration, night humidity peaks, and temperature accumulation patterns—rather than daytime averages recorded by district weather stations. Smart traps therefore did more than insect counting; they served as phenology indicators, enabling forecasting engines to predict breeding surges before crop damage crossed economic thresholds. Extension systems used these curves to decide when advisories should shift from monitoring alerts to action advisories, triggering synchronized pest response at community scale.

5. GIS-Enabled Pest Mapping and Community Risk Zoning

Geographic Information Systems (GIS) provided spatial intelligence that enhanced entomological advisory precision. Pest data points from farms, smart traps, and community scouts were aggregated into GIS dashboards that visualized heat zones, outbreak clusters, and spread trajectories. These maps helped extension planners understand pest movement as a spatial process rather than isolated farm events. In the case of invasive and migratory pests, GIS layers were fused with wind direction grids, elevation maps, vegetation cover, rainfall anomalies, and cropping system clusters. This generated block-level pest risk zones, which were then translated into localized advisories, bio-agent release corridors, and targeted chemical intervention windows. Extension officers coordinated with FPO leaders, SHGs, and panchayat bodies to ensure that advisories were socially synchronized. GIS visual outputs were increasingly used in village meetings, community training sessions, and digital display boards, allowing farmers to visually perceive risk zones and outbreak probability. This collective visualization strengthened risk perception and compliance behaviour, preventing scattered responses that weakened community pest control.

6. IoT Micro-Climate Data and Pest Forecasting Accuracy

IoT-enabled micro-climate sensors played a crucial role in entomological forecasting. Near-farm sensors recorded humidity peaks, night temperature, soil moisture, wind speed, rainfall intensity, and leaf wetness duration—parameters that directly influenced insect oviposition, larval survival, migration behaviour, and population bursts. Unlike district weather readings, these micro-climate datasets represented actual pest-habitat conditions, enabling forecasting models to process localized environmental response variables. Degree-day models predicted pest emergence timing based on accumulated thermal units, while humidity threshold models predicted breeding bursts once relative humidity crossed species-specific tolerance limits. These climate-pest correlations enabled extension systems to generate probability-based outbreak forecasts and pre-emptive advisory triggers rather than delayed damage assessments.

7. Social Media Extension Systems as Real-Time Advisory Channels

Social media groups emerged as decentralized pest intelligence hubs. Farmers shared images, short videos, and voice messages documenting pest behaviour, natural enemy presence, and early infestation symptoms. Extension experts moderated these groups and translated field narratives into actionable advisories. The conversational nature of these groups strengthened advisory trust, while the immediacy improved information velocity. In several Indian states, extension agencies formalized crop-pest alert groups, integrating expert-validated entomology content in local languages. These advisories carried not only spray windows but also safety instructions, pollinator risk tagging, biological control recommendations, trap density advice, and synchronized community action appeals. The groups also acted as feedback loops, where farmers posted post-advisory compliance updates, which were monitored to refine future advisory triggers.

8. Extension Training Systems for Surveillance Literacy and Behavioural Adoption

Digital surveillance adoption increased significantly when paired with participatory extension training. Farmer Field Schools (FFS) and Capacity Building Workshops trained farmers and extension workers on insect ecology, pest phenology, trap interpretation, ETL literacy, bio-agent differentiation, digital reporting formats, safety tagging, and advisory compliance behaviour. Youth pest scouts were increasingly integrated into surveillance cooperatives where gamified reporting modules improved engagement. Extension systems also introduced behavioural nudges, reminding farmers when ETL crossed action thresholds, reinforcing biological control compliance, and discouraging indiscriminate chemical sprays. This training reduced spray panic psychology and promoted evidence-based pest decision behaviour.

9. Impacts of Digital-Participatory Surveillance on Pest Advisory Compliance

Field studies and extension assessments documented multiple systemic impacts. Surveillance density increased manifold due to crowdsourced pest data capture and IoT-linked smart traps. Advisory latency reduced significantly, allowing farmers to receive warnings before pest pressure crossed economic injury levels. Precision drone spray demonstrations showed 30–60% reduction in pesticide load when advisories were spatially triggered. The biggest impact was behavioural: indiscriminate insecticide sprays declined sharply in villages practicing participatory pest validation loops, ETL-based advisories, and community synchronized action appeals. Farmers adopted biological control agents and pollinator-risk tagged advisories more willingly when digital tools were paired with trust validation and participatory literacy modules.

10. Future Outlook

The next decade would witness deeper integration of AI insect acoustic monitoring, automated ETL-based advisory nudges, federated pest learning models, migration-linked pest forecasts, community-owned pest intelligence cooperatives, and stronger integration of participatory entomology data into national advisory grids. Extension entomology would evolve further into farmer-centric digital advisory ecosystems rather than expert-centric monitoring units.

11. Conclusion

The convergence of digital tools and participatory extension systems fundamentally reshaped insect pest surveillance, forecasting, and advisory delivery. These systems embedded entomological precision within social communication networks, enabling early outbreak recognition, localized forecasting, personalized advisories, ecological safety tagging, and socially synchronized pest response. The chapter reaffirmed that future agricultural advisory systems must treat pest surveillance as both an insect ecology process and a community communication system, empowering farmers to act early, act accurately, and act collectively for sustainable pest management.

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PLASMA TECHNOLOGY FOR SUSTAINABLE PEST MANAGEMENT IN AGRICULTURE

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ABSTRACT

Plasma technology has emerged as a promising non-chemical approach for sustainable pest management in modern agriculture. Increasing concerns over pesticide resistance, environmental contamination, and food safety have necessitated the development of alternative pest control strategies compatible with climate-smart agriculture. Cold atmospheric plasma (CAP) and plasma-activated water (PAW) generate reactive oxygen and nitrogen species that effectively suppress insect pests, plant pathogens, and nematodes without leaving toxic residues. Plasma-based treatments can be applied directly to pests, seeds, soil, and harvested produce, offering multifaceted benefits such as pest mortality, pathogen inactivation, and enhancement of plant defense responses. This chapter reviews recent advances in plasma technology for agricultural pest management, highlighting application methods, mechanisms of pest suppression, and integration with integrated pest management (IPM) systems. Environmental benefits, challenges, and future research directions are also discussed to evaluate the potential of plasma technology as a sustainable and climate-smart pest management tool.

Keywords: Plasma technology, Sustainable pest control, Plasma-activated water, Climate-smart agriculture

Introduction

Sustainable pest management is essential for ensuring global food security while minimizing the adverse environmental impacts of agriculture. Conventional pest control practices rely heavily on synthetic pesticides, which have contributed to the development of pesticide resistance, contamination of soil and water resources, biodiversity loss, and health risks to humans and non-target organisms. These challenges have intensified the search for alternative, eco-friendly pest management technologies that align with the principles of sustainable and climate-smart agriculture. Plasma technology has recently gained attention as an innovative and non-chemical tool for pest control in agricultural systems. Plasma, often referred to as the fourth state of matter, consists of a partially ionized gas containing electrons, ions, reactive species, ultraviolet radiation, and electric fields. In agricultural applications, non-thermal or cold atmospheric plasma (CAP) is particularly relevant because it operates at near-ambient temperatures, making it suitable for treating biological materials such as seeds, plants, insects, and harvested produce without causing thermal damage.

The pest management potential of plasma technology lies in its ability to generate reactive oxygen and nitrogen species (RONS), including ozone, hydrogen peroxide, hydroxyl radicals, and nitrogen oxides. These reactive species induce oxidative stress, disrupt cellular structures, and interfere with physiological processes in pests and pathogens. Plasma treatments have been reported to effectively control insect pests, fungal and bacterial pathogens, nematodes, and storage pests, while also reducing pesticide residues on agricultural commodities. In addition to direct pest suppression, plasma technology can enhance plant resistance to pests by stimulating defense-related biochemical and molecular pathways. Plasma-activated water (PAW), produced by exposing water to cold plasma, and has emerged as a versatile tool that can be applied as a foliar spray, soil drench, or seed treatment. PAW combines antimicrobial activity with plant growth-promoting effects, making it particularly attractive for integrated pest management (IPM) systems. Despite its potential, plasma technology is still at an early stage of adoption in agriculture, with most studies conducted under laboratory or controlled conditions. Understanding the mechanisms of pest suppression, optimizing treatment parameters, and evaluating field-scale applications are critical for its wider implementation. This chapter provides a comprehensive overview of plasma technology for sustainable pest management, focusing on application approaches, underlying mechanisms, environmental benefits, challenges, and future prospects within the context of climate-smart agriculture.

Fundamentals of plasma technology relevant to pest control

Plasma Definition and Types

Plasma is an ionized gas composed of electrons, ions, reactive species (RONS: reactive oxygen and nitrogen species), UV photons, and electric fields. In agricultural contexts, cold atmospheric plasma (CAP) and dielectric barrier discharge (DBD) plasmas are most commonly used due to their mild operating temperatures and biological compatibility.

Plasma-based pest management approaches

Plasma technology can be applied for pest management through direct and indirect approaches, depending on the target pest and cropping system. Direct plasma exposure involves treating pests, seeds, or produce surfaces with cold plasma, resulting in rapid pest mortality or pathogen inactivation. This approach is particularly effective for seed-borne pathogens, storage pests, and post-harvest disease management. Plasma-activated water (PAW) represents an indirect but highly versatile approach for pest control. PAW contains long-lived reactive species such as hydrogen peroxide, nitrates, and nitrites, which suppress microbial pathogens and reduce pest pressure when applied as foliar sprays or soil drenches. PAW has also been reported to reduce insect egg viability and nematode activity in soil while enhancing plant vigour. Seed treatment using plasma has gained considerable attention as it simultaneously disinfects seed surfaces and improves germination and seedling vigour. Plasma-treated seeds exhibit reduced early-stage pest and disease incidence, contributing to better crop establishment. Post-harvest applications of plasma are effective in controlling storage insects and fungal pathogens while maintaining produce quality.

Table 1. Plasma-based pest management approaches in agriculture

Application method	Target pests/pathogens	Key effects
Direct cold plasma exposure	Insects, fungi, bacteria	Cell damage, pest mortality
Plasma-activated water (PAW)	Pathogens, insect eggs, nematodes	Growth inhibition, reduced viability
Plasma seed treatment	Seed-borne pests and pathogens	Disinfection, improved vigor
Post-harvest plasma treatment	Storage pests, spoilage fungi	Extended shelf life, residue-free control

Mechanisms of pest suppression by plasma technology

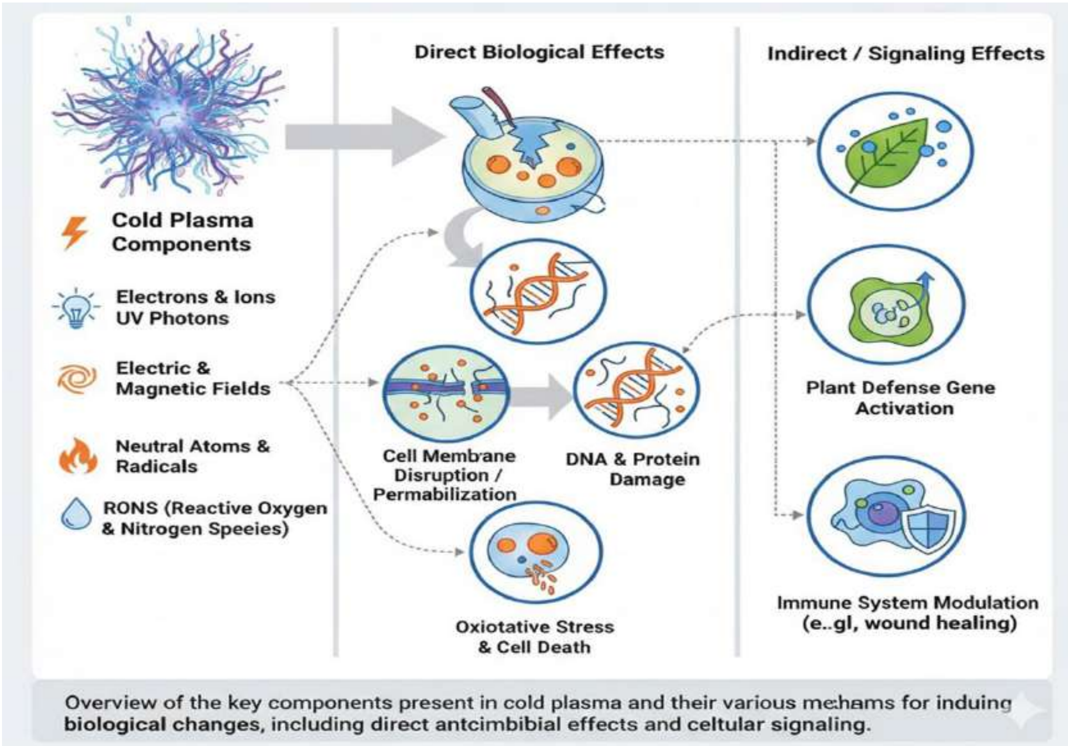
The effectiveness of plasma technology in pest management is primarily attributed to physical, chemical, and biological mechanisms induced by plasma-generated components. Reactive oxygen and nitrogen species (RONS) play a central role by inducing oxidative stress in pest organisms. Excessive oxidative stress disrupts cell membranes, denatures proteins, and damages nucleic acids, ultimately leading to pest mortality. In insects, plasma exposure damages the cuticle, interferes with respiration, and disrupts nervous system functioning. Sub-lethal plasma doses can reduce feeding activity, growth rate, and reproductive potential, thereby lowering pest population pressure. Plasma-generated electric fields and charged particles further contribute to physiological stress and cellular dysfunction.

For microbial pests such as fungi and bacteria, plasma causes cell wall rupture, membrane permeability changes, and DNA fragmentation. These effects inhibit spore germination, mycelial growth, and pathogen infectivity. In soil-borne pests and nematodes, plasma and PAW alter the soil microenvironment, reducing pest survival and mobility. In addition to direct pest suppression, plasma technology induces indirect mechanisms through plant defence activation. PAW-mediated signalling enhances antioxidant enzyme activity, phenolic compound accumulation, and expression of defence-related genes in plants. This induced resistance improves the plant's ability to withstand pest attacks and reduces dependence on chemical pesticides.

Table 2. Mechanisms of plasma-induced pest suppression

Plasma component	Target	Mechanism
Reactive oxygen species	Insects, microbes	Oxidative stress, membrane damage
Reactive nitrogen species	Pathogens	Enzyme inhibition, DNA damage
UV radiation	Microorganisms	Nucleic acid disruption
Electric fields	Insects	Physiological and behavioral disruption
PAW-induced signaling	Plants	Activation of defense pathways

Figure 1: Components of Cold Plasma and Mechanisms of Action, illustrates the dual pathway of how cold plasma (and its liquid derivative, PAW) suppresses pests and strengthens crops. The diagram is essentially divided into two halves to show the Direct vs. Indirect biological pathways.



I. Direct Effects: The "Pest Attack" Phase

- This side of the diagram depicts a pest (the purple insect) being directly bombarded by cold plasma components.
- RONS Interaction: Reactive Oxygen and Nitrogen Species (RONS) like hydroxyl radicals and ozone attack the cell membranes of the pest.
- Oxidative Stress: The diagram indicates a transition where these species penetrate the pest, causing "Oxidative stress → cell damage." This is often represented by a "skull" icon or damaged cellular structures.
- Growth Interference: The final stage in this sequence shows the pest becoming debilitated, leading to "Interference with pest feeding/growth."

II. Indirect Effects: The "Plant Defense" Phase

- This side of the diagram shows a plant (the green seedling) being treated with a droplet of PAW (Plasma-Activated Water).
- PAW-Induced Activation: The droplet containing stable RONS (like nitrates and hydrogen peroxide) acts as a signal to the plant.

- Gene Activation: The diagram shows a DNA helix and a shield icon, representing the "PAW-induced plant defense gene activation."
- Enhanced Resistance: The arrows pointing upward along the plant stem indicate systemic resistance, where the plants own immune system is "primed" to fend off future pest attacks.

Recent plasma technology applications in pest management

Study	Plasma Type	Target	Key Findings	Reference
Fall Armyworm control in rice	Cold plasma + PAW	*Spodoptera frugiperda*	Reduced feeding, growth, higher mortality	Dilip (2025)
Post-harvest wheat pests	Plasma-activated gas	Stored grain pests	Efficient pest and microbial inactivation without quality loss	Food Control (2025)
Plant defense responses	PAW irrigation	Tomato seedlings	Upregulated defense genes and improved resistance	PAW study (2025)
Broad plasma agriculture review	NTP/PAW	Pathogens/pests	Overview of plasma tech and pest/pathogen suppression	Kolik et al. (2023)
Comprehensive NTP review	Non-thermal plasma	Seeds/food processing	Sustainable tech overview, relevant pest/pathogen control	NTP review (2025)

Role in integrated pest management (IPM)

Integrated Pest Management (IPM) emphasizes the use of multiple, compatible pest control strategies to minimize economic damage while reducing environmental and health risks. Plasma technology fits well within IPM frameworks due to its non-chemical mode of action, residue-free nature, and compatibility with biological and cultural pest management practices. Unlike conventional pesticides, plasma-based interventions do not rely on specific biochemical targets, thereby reducing the risk of pest resistance development. Figure 2 shows, residue-free technology provides a sustainable alternative to chemical pesticides by killing pests while simultaneously "priming" crops for long-term resistance. Together, these mechanisms offer a multi-layered, eco-friendly approach to Integrated Pest Management (IPM).

Figure 2. Plasma-enabled IPM approach for sustainable pest management

Plasma technology can be strategically incorporated at different stages of crop production. Plasma seed treatment provides an effective preventive measure by eliminating seed-borne pests and pathogens and enhancing early seedling vigor, thereby reducing initial pest pressure. Plasma-activated water (PAW) can be used as a foliar spray or soil drench to suppress microbial pathogens, insect eggs, and nematodes, complementing biological control agents such as parasitoids, predators, and microbial biopesticides. Since plasma treatments do not leave toxic residues, they are generally safe for beneficial organisms, making them suitable for IPM programs.

In post-harvest systems, plasma technology can be integrated with physical and biological control methods to manage storage pests and reduce post-harvest losses without chemical fumigants. Plasma treatments can also be combined with reduced doses of conventional pesticides to enhance efficacy while lowering overall chemical input. This integrated approach supports resistance management, prolongs pesticide effectiveness, and reduces environmental contamination. Overall, plasma technology enhances the flexibility and sustainability of IPM by providing a novel physical and chemical stress-based control method. Its integration into IPM programs contributes to long-term pest suppression, ecosystem stability, and sustainable crop protection under diverse agroecological conditions.

Environmental and climate smart benefits

Plasma-based pest management reduces reliance on synthetic pesticides, thereby minimizing soil and water contamination, lowering greenhouse gas emissions associated with agrochemical production, and fostering resilient agroecosystems. Plasma technology offers significant environmental and climate-smart benefits by reducing reliance on synthetic pesticides and contributing to sustainable agricultural intensification. Conventional pesticide production, transportation, and application are energy-intensive processes that generate greenhouse gas emissions and cause soil, water, and air pollution. By contrast, plasma-based pest management relies primarily on electricity and gases such as air or nitrogen, enabling cleaner and more efficient pest control systems.

The residue-free nature of plasma treatments minimizes chemical accumulation in soil, water bodies, and food products, thereby protecting non-target organisms, pollinators, and soil biodiversity. Plasma-activated water enhances microbial balance in soil while suppressing harmful pathogens, contributing to improved soil health and agroecosystem resilience. These benefits are particularly relevant under climate change scenarios, where stressed crops are more vulnerable to pest outbreaks. Plasma technology also aligns with climate-smart agriculture by improving resource-use efficiency. Enhanced seed vigor and plant defense responses reduce crop losses and input requirements, indirectly lowering the carbon footprint of agricultural production. Furthermore, plasma systems can be powered by renewable energy sources such as solar or wind power, strengthening their role in low-carbon farming systems. By reducing chemical inputs, enhancing crop resilience, and supporting sustainable intensification, plasma technology contributes to mitigation and adaptation strategies under climate change. Its adoption supports environmentally sound pest management while maintaining productivity and food security.

Challenges and future prospects

Despite its promising potential, the widespread adoption of plasma technology in agricultural pest management faces several challenges. One of the primary constraints is the high initial cost of plasma generation equipment, which may limit adoption by small and marginal farmers. In addition, most plasma-based pest management studies have been conducted under laboratory or controlled conditions, with limited field-scale validation across diverse crops, pests, and agroecological regions. The lack of standardized treatment protocols, including plasma type, exposure duration, intensity, and application frequency, presents another challenge. Variability in these parameters can lead to inconsistent results, making it difficult to develop uniform recommendations for farmers. Energy requirements and system durability under field conditions also need further optimization.

Future research should focus on developing cost-effective, portable, and scalable plasma devices suitable for on-farm use. Long-term field experiments are necessary to evaluate ecological impacts, non-target effects, and economic feasibility. Integration of plasma technology with precision agriculture, automation, and digital decision-support systems could further enhance its effectiveness and adoption. Additionally, policy support, farmer training, and interdisciplinary collaboration will be essential to translate plasma technology from experimental research to practical agricultural applications.

Conclusion

Plasma technology represents a novel and sustainable approach to pest management in agriculture, offering effective pest suppression without the environmental drawbacks associated with chemical pesticides. Its ability to integrate seamlessly with IPM strategies, enhance plant defense responses, and reduce chemical inputs makes it highly relevant under climate-smart agriculture frameworks. Although challenges related to cost, standardization, and field-scale application remain, continued technological advancements and research are expected to overcome these limitations. With appropriate development and integration, plasma technology has the potential to transform sustainable pest management and contribute significantly to resilient and environmentally responsible agricultural systems

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INFLUENCE OF FARMER FIELD SCHOOL ON COMMUNITY-LEVEL IPM ADOPTION AND SUSTAINABLE INSECT PEST CONTROL BEHAVIOUR AMONG VEGETABLE GROWERS

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ABSTRACT

Vegetable farming ensures rural income and nutrition but faces high losses from mobile insect pests. Routine calendar-based pesticide use drives resistance, resurgence, natural-enemy loss, health risks, and residue-linked market rejection. Farmer Field School (FFS), a season-long participatory extension approach, strengthens entomological knowledge, pest identification, monitoring skills, AESA-based decision making, and community norms supporting sustainable IPM. FFS promotes collective surveillance using pheromone and sticky traps, sanitation, and biopesticides such as neem, chilli-garlic extracts, Bt, and NPV. FFS communities report 30–60% fewer chemical sprays, 2–3× higher trap monitoring, and 40–70% adoption of 3+ IPM practices. Constraints include weak bio-input supply, labor demand, limited follow-up, and poor pesticide-free market incentives. Convergence, alumni networks, and institutional support are key to sustaining community IPM behavior.

Key words: Farmer Field School (FFS); Community IPM Adoption; Sustainable Pest Control Behavior

1. Introduction

Vegetable cultivation contributes significantly to rural income and nutritional security, but the sector suffers from serious yield losses due to insect pests such as fruit borers, sucking pests, leaf miners, and defoliators. Many farmers adopt pesticide-centric schedules instead of decision-based spraying, resulting in pest resistance, resurgence, destruction of beneficial insects, environmental contamination, health hazards, and residue-related market rejection. Sustainable pest management in vegetables requires collective understanding, coordinated action, and continuous behavioral reinforcement at the community level. Farmer Field School (FFS), a participatory and experiential extension model, provides an effective platform for strengthening farmers' ecological literacy and promoting Integrated Pest Management (IPM) adoption. Unlike conventional training approaches, FFS emphasizes field-based discovery learning, making pest management a community-driven practice rather than an individual farm decision.

Farmer Field School (FFS): Concept and Extension Significance

Farmer Field School is a season-long, group-based learning approach where farmers conduct experiments, observe crop ecology, analyze agro-ecosystems, and make decisions collectively under the guidance of a trained facilitator. The approach is grounded in adult learning principles, peer exchange, and hands-on field diagnostics, enabling farmers to translate scientific recommendations into practical local solutions. From an extension perspective, FFS strengthens social capital, improves risk communication, and accelerates technology diffusion through farmer-to-farmer learning pathways. Since pest outbreaks in vegetables are highly spatial and mobile, FFS creates synchronized learning communities capable of taking area-wide pest management decisions. This makes FFS not only a training tool but also a behavioral change engine that promotes community norms supporting sustainable pest control choices.

Integrated Pest Management (IPM) in Vegetable Ecosystems

Integrated Pest Management is an ecologically balanced strategy that combines cultural, mechanical, biological, botanical, and need-based chemical methods to maintain pest populations below economic injury levels. In vegetable systems, IPM adoption demands accurate pest identification, life cycle awareness, and real-time monitoring, as pest damage rapidly influences marketable yield. Key entomological components include field scouting, pheromone and sticky traps, conservation of predators and parasitoids, use of microbial agents such as *Bacillus thuringiensis* (Bt), nucleopolyhedrovirus (NPV), neem-based botanicals, and habitat-based natural enemy protection. Since vegetables host multiple pest complexes simultaneously, farmers must learn pest–predator balance, threshold-based decisions, and eco-friendly bio-input integration. FFS facilitates this learning through weekly field observation cycles, live insect diagnosis, and group-driven pest management planning.

Community-Level IPM Adoption: Importance

Community-level adoption of IPM becomes essential in vegetable cultivation because most major insect pests are highly mobile and spread across farm boundaries within days. When a village or cluster adopts coordinated pest monitoring and synchronized suppression practices, the overall pest pressure reduces, benefitting even small and marginal farmers. Collective surveillance enables early detection of invasive pests, improves reporting efficiency, and strengthens shared ownership of pest management responsibilities. Social learning theory indicates that adoption increases when farmers witness peer success, trust community validation, and observe consistent group behavior. FFS serves as a catalyst for such community learning, creating pest-literate farmer groups that promote shared monitoring systems, community-based threshold decisions, and joint action against outbreaks.

Sustainable Insect Pest Control Behavior: A Behavioral Perspective

Sustainable pest control behavior refers to long-term farmer practices that prioritize ecological safety, minimize chemical dependency, protect beneficial insects, and align with residue-safe market standards. Behavioral change in pest management is influenced not only by technical knowledge but also by perceived risk, economic incentives, labor feasibility, community norms, peer influence, and institutional reinforcement. Many farmers continue pesticide overuse due to habitual spraying patterns, fear of sudden crop loss, or lack of confidence in pest diagnosis. FFS impacts these behavioral determinants by improving pest monitoring confidence, enabling field-based decision making, reinforcing collective norms, and promoting ecological risk perception. Through continuous interaction and field validation, sustainable pest management becomes a socially accepted community practice.

How FFS Influences Community-Level IPM Adoption

FFS influences community-level IPM adoption through experiential learning, skill building, and peer-network reinforcement mechanisms. Agro-ecosystem analysis (AESA) sessions help farmers understand insect ecology, predator conservation, and crop health indicators through direct observation. Group-based scouting improves pest identification accuracy and encourages synchronized decisions on when and how to apply control measures. Peer learning accelerates adoption through social proof, where farmers replicate practices tested and validated by fellow growers. Facilitator-supported field diagnosis ensures scientific accuracy, especially in differentiating pest damage from disease or nutrient stress symptoms. Over time, these processes internalize sustainable pest control behavior, transforming individual learning into community-driven IPM action.

FFS in Strengthening Pest Surveillance and Community Action

FFS strengthens pest surveillance by training farmers to conduct weekly crop ecology observations, insect identification, and trap-based monitoring. Farmers commonly establish shared pest reporting groups, community trap adoption systems, and synchronized sanitation practices such as removal of infested plant parts, field hygiene, rogueing, and light or color traps for mass monitoring of sucking pests. Many FFS alumni groups create informal village pest surveillance schedules, enabling early alerts and coordinated suppression decisions. Such collective surveillance reduces infestation intensity, prevents pest spillover across farms, and improves overall entomological decision-making accuracy. FFS thus enhances both extension efficiency and pest monitoring precision at the community level.

eduction of Chemical Pesticide Dependence through FFS

A major outcome of FFS training is the shift from calendar-based spraying to need-based spraying supported by pest threshold decisions. Farmers increasingly adopt botanicals like neem extracts, chilli-garlic solutions, Bt and NPV formulations, and color sticky traps for aphids, whiteflies, and thrips. Conservation of natural enemies such as spiders, ladybird beetles, lacewings, and parasitoid wasps improves due to better ecological understanding and reduced broad-spectrum chemical use. Spray rounds often decline as farmers gain confidence in pest monitoring and recognize the long-term risks of chemical overuse. This reduction indicates that FFS successfully reshapes sustainable pest control behavior while protecting beneficial insect populations.

Constraints in Community-Level IPM Adoption even after FFS

Although FFS improves adoption, challenges remain due to inconsistent availability of biocontrol and botanical inputs, higher labor requirements for pest monitoring, non-synchronization of IPM practices by neighboring non-FFS farmers, weak price incentives for pesticide-free vegetables, and inadequate post-training institutional follow-up. Many farmers also remain risk-averse during sudden outbreaks due to fear of economic loss or lack of rapid advisory support. Market linkages for residue-safe or organic produce are still evolving in many regions, reducing motivation for chemical-free IPM adoption. These constraints highlight the need for structured institutional reinforcement to sustain FFS-led community IPM behavior.

Extension Strategies to Strengthen FFS-Led IPM Adoption

To scale FFS-driven IPM sustainably, extension systems should integrate post-FFS refresher AESA sessions, regular field follow-ups, community pest surveillance committees, linkages with entomology labs for rapid diagnosis, assured supply of bio-inputs, digital advisory networks for FFS alumni, market incentives for residue-safe produce, and stronger inclusion of youth and women in pest monitoring networks. Case documentation and village-level campaigns can further reinforce social proof and community adoption. Institutional convergence between extension units and entomology advisory centers will ensure long-term community behavioral reinforcement and sustainable pest control choices.

Farmer Field School significantly influences community-level IPM adoption and sustainable insect pest control behavior among vegetable growers by enhancing ecological understanding, pest surveillance skills, group-driven decision making, and peer-validated practice diffusion. To ensure long-term sustainability, FFS initiatives must be reinforced through structured follow-up, assured bio-input access, institutional convergence with entomology advisory systems, and market incentives for residue-safe produce. FFS thus stands as a powerful model for enabling community-driven sustainable insect pest management in vegetable ecosystems.

Impact Indicators for FFS Influence in Vegetable IPM

Impact measurement of FFS influence can include knowledge gain scores, pest identification accuracy percentage, monitoring frequency index, trap adoption rate, natural enemy conservation index, number of spray rounds reduced, biopesticide adoption percentage, decision-making confidence scale, and community IPM synchronization index. These indicators help future researchers assess both behavioral change and entomological skill improvements attributable to FFS training. In many vegetable-growing FFS communities, farmers demonstrate 30–60% reduction in chemical spray frequency, 2–3 times higher trap-based pest monitoring, 40–70%

adoption of 3 or more IPM practices, improved natural enemy conservation, and greater confidence in threshold-based spraying decisions. Informal pest surveillance networks become active post-training, enabling early warning and coordinated action. These outcomes illustrate how FFS transforms scientific entomology learning into sustainable community pest control behavior.

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SKYFOX PUBLISHING GROUP
SKYFOX PRESS
#1789, MEDICAL COLLEGE ROAD
THANJAVUR-613004 TAMIL NADU,
INDIA.

ISBN 978-93-90357-33-8

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