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Pheromone-Based Technologies for Sustainable Management of Agricultural Insect Pests

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Pheromones are species-specific chemical signals that regulate communication and reproductive behaviour in insects and have become important tools for sustainable agricultural pest management. Pheromone-based technologies include monitoring and detection, mass trapping, mating disruption and attract-and-kill approaches. Among these, pheromone traps are widely used for early detection, seasonal monitoring, population trend assessment and timing of control measures, while mating disruption can suppress reproduction by interfering with the ability of males to locate females. These approaches can reduce reliance on broad-spectrum insecticides, conserve beneficial organisms and provide highly targeted pest management. However, efficacy is influenced by pest biology, population density, landscape structure, wind, temperature, formulation, dispenser longevity and the spatial scale of deployment. Recent advances in semiochemical discovery, synthetic chemistry, slow-release formulations, automated trapping, image analysis, Internet of Things technologies and precision agriculture are expanding the potential of pheromone-based systems. Successful adoption requires integration with scouting, economic thresholds, biological control, cultural practices and selective chemical interventions. This review summarizes the biological basis, major technologies, monitoring applications, mating disruption, mass trapping, attract-and-kill systems, formulation and delivery, current limitations, Indian agricultural relevance and future prospects of pheromone-based pest management.

Introduction

Insect pests cause substantial quantitative and qualitative losses in agricultural crops, and their management has historically depended heavily on chemical insecticides. Although insecticides remain important, intensive use can contribute to resistance, residues, disruption of natural enemies and environmental contamination. Pheromone-based technologies offer a different approach by exploiting the natural chemical communication systems of insects to monitor or manipulate pest behaviour. Insect pheromones are chemical signals released by individuals and detected by members of the same species. Sex pheromones are particularly important in agriculture because they can attract mates, allowing synthetic analogues to be used for surveillance and behavioural manipulation. Other semiochemicals, including aggregation pheromones, can also be exploited to concentrate pests in traps or treated locations. The high specificity of many insect pheromones is a major advantage. A pheromone trap can target a particular pest species without exposing the entire arthropod community to a toxicant. This specificity makes pheromone technologies especially suitable for integrated pest management (IPM), where the objective is to maintain pest populations below economically damaging levels while minimizing unnecessary pesticide use. Pheromone-based systems should not, however, be regarded as universal replacements for insecticides. Their performance depends on pest population density, insect behaviour, landscape scale, weather, trap design, pheromone release rate and correct deployment. The most effective approach is generally to integrate pheromone information and behavioural control with biological, cultural and selective chemical tactics.

Biological Basis of Insect Pheromone Communication

Pheromone communication involves production, release, dispersal and perception of chemical signals. In many moth species, females release sex pheromones that are detected by highly sensitive olfactory receptors on male antennae. Males can orient toward pheromone plumes using wind direction and intermittent odour contact. Synthetic pheromone formulations reproduce key chemical components of these signals and can therefore be used to attract insects or interfere with their normal orientation. Pheromone blends can contain one or several compounds in defined ratios. Species specificity may depend not only on the chemical identity of the components but also on their relative proportions, release rate and environmental context. Consequently, formulation and dispenser design are as important as chemical synthesis when developing a field technology.

Pheromone communication is also influenced by temperature, wind, atmospheric stability, vegetation and insect physiological state. These factors affect both pheromone release and the ability of insects to locate the source. Understanding these biological and environmental interactions is essential for reliable field deployment.

Major Pheromone-Based Technologies

The principal agricultural applications of pheromones can be grouped into monitoring and trapping, mass trapping, mating disruption and attract-and-kill systems. These approaches differ in their objective: monitoring measures pest activity; mass trapping seeks to remove adults; mating disruption interferes with reproduction; and attract-and-kill combines behavioural attraction with a lethal treatment.

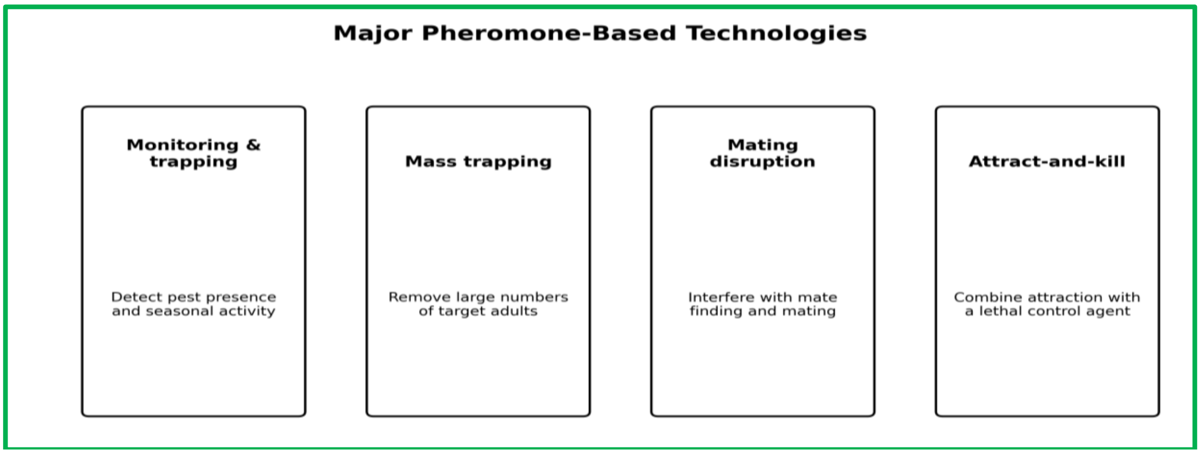

Figure 1. Major pheromone-based technologies used for monitoring and sustainable management of agricultural insect pests

Pheromone Traps for Pest Monitoring

Pheromone traps are among the most widely used applications of insect pheromones. A trap contains a synthetic pheromone lure that attracts the target pest into a collection device. Trap catches can provide information on pest presence, seasonal emergence, population trends and movement into a crop. Monitoring is valuable because pest abundance can vary substantially during the crop cycle. Regular trap observations can identify the beginning of adult activity and help synchronize field scouting and management interventions with pest development. Trap data can also be used to compare pest pressure among fields or seasons. The interpretation of trap counts should be based on locally validated thresholds rather than universal numbers. Trap design, lure type, lure age, trap height, placement density, sampling interval and environmental conditions can all affect captures. Trap catches should therefore be combined with field observations and crop phenology before making management decisions.

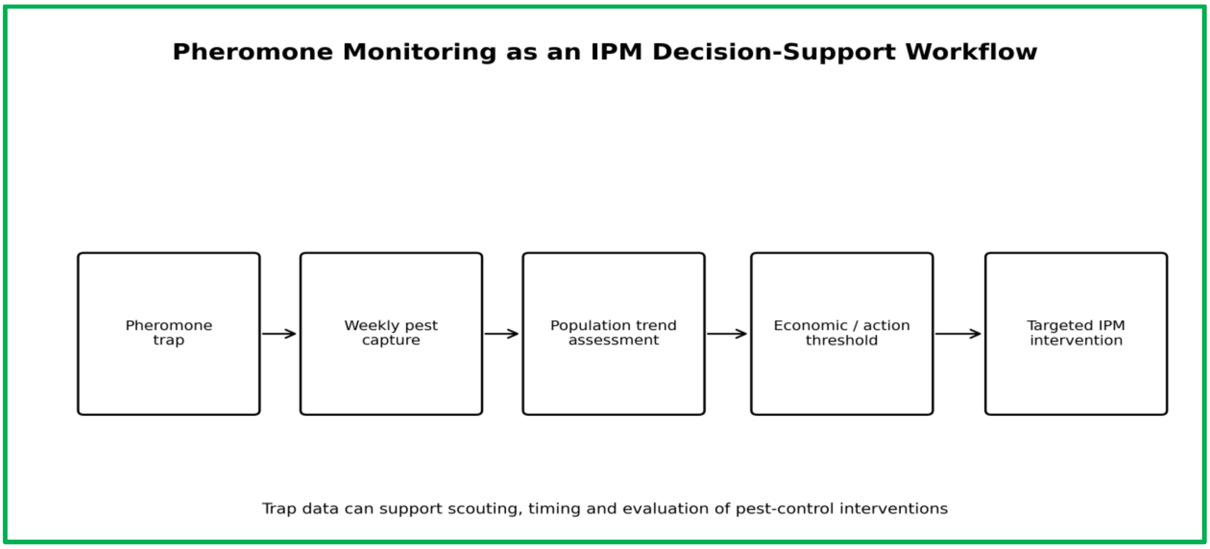

Figure 2. General workflow showing how pheromone trap catches can be converted into pest-monitoring information and IPM decisions

Mass Trapping

Mass trapping uses pheromone-baited traps at a density intended to remove a substantial proportion of the target pest population. The approach is most likely to be effective when the pest has a strong attraction to the pheromone, the target population is not excessively large and trap density can intercept a meaningful proportion of dispersing adults. The success of mass trapping depends strongly on deployment scale and timing. If traps are introduced after the pest population has already reached a high density, removal of a portion of adults may not prevent crop damage. Landscape-level deployment can be more effective for mobile pests because insects can move between neighbouring fields. Therefore, coordination among growers can improve the probability of success. Mass trapping can reduce insecticide applications and is particularly attractive for pests that respond strongly to aggregation or sex pheromones. However, trap maintenance, lure replacement, disposal and labour requirements should be considered when evaluating economic feasibility.

Mating Disruption

Mating disruption is one of the most sophisticated pheromone-based technologies. Instead of attracting insects into a trap, synthetic pheromone is released throughout the crop so that males experience an environment containing multiple pheromone sources. This can interfere with orientation toward females and reduce successful mating.

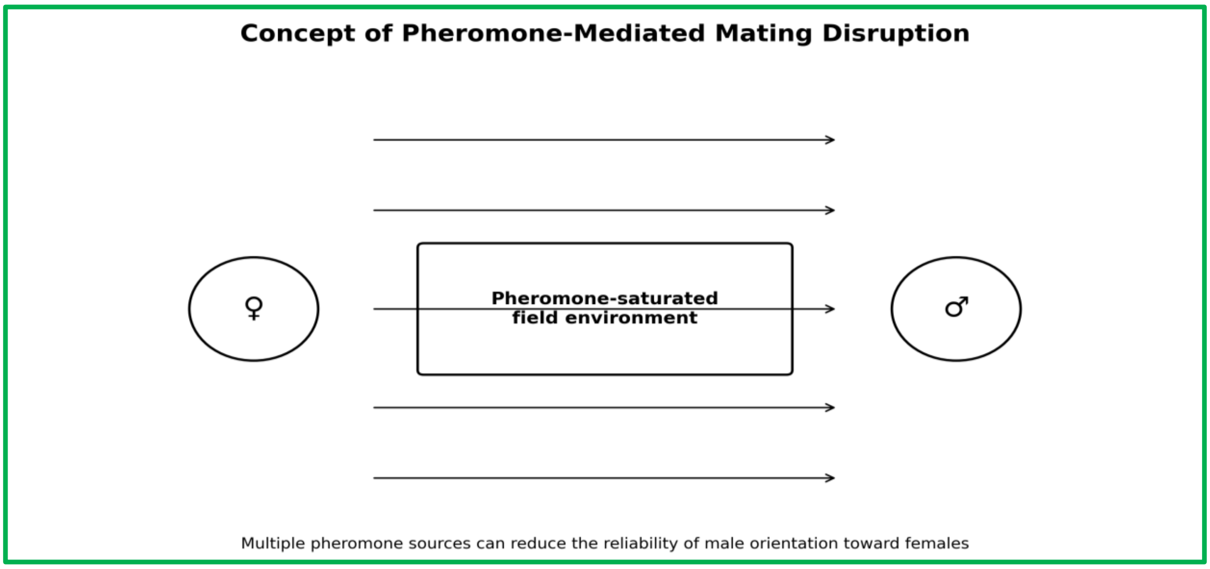

Figure 3. Conceptual representation of mating disruption, in which a pheromone-saturated environment interferes with successful male orientation and mate finding

Mating disruption can be highly effective when deployed before or at the beginning of the mating period and when pheromone coverage is sufficiently uniform. It is generally most suitable for pests with well-characterized sex pheromones and relatively predictable mating behaviour. Large contiguous areas can improve performance because immigration from untreated fields may reduce control. Mechanisms contributing to disruption can include competition between synthetic and natural pheromone sources, sensory adaptation or habituation, false-source orientation and confusion caused by multiple odour plumes. The relative importance of these mechanisms varies among pest species and formulation systems. Mating disruption has the potential to reduce pesticide dependence and preserve natural enemies because its direct target is pest communication rather than a broad physiological process. Nevertheless, it may be less effective when pest density is extremely high or when treated areas are small and surrounded by untreated sources.

Attract-and-Kill Systems

Attract-and-kill combines a behavioural attractant with a lethal agent. Instead of treating the entire crop canopy, a concentrated source is designed to attract the target insect to a small treated area. Depending on the system, the lethal component may be an insecticide, toxicant or biological agent. The concept can reduce the quantity of pesticide applied per hectare while maintaining behavioural targeting. It is particularly attractive where the pest has a strong response to a pheromone or food-based lure. Formulation stability, attraction distance, kill speed and avoidance behaviour are important factors influencing performance. Attract-and-kill should be evaluated carefully for non-target exposure, particularly where attractants may draw beneficial insects. Target specificity of the semiochemical is therefore a major consideration in product development.

Pheromone-Based Management of Important Crop Pests

Pheromone technologies have been developed for numerous agricultural pests, particularly moths and some beetles. Applications include monitoring and management of fruit moths, leafrollers, bollworms, stem borers, fruit flies and stored-product insects. The appropriate technology depends on the pest's communication system and population ecology. In fruit crops, pheromone monitoring can assist in identifying adult emergence and timing control against vulnerable immature stages. In cotton and other field crops, pheromone traps can contribute to monitoring of bollworm complexes and other target pests. In protected cultivation, pheromone traps can support early detection because enclosed environments allow more controlled trap placement and monitoring. Stored-product systems can benefit from pheromone trapping because insects often develop within enclosed facilities where traps can be systematically distributed. Monitoring can detect low-density infestations before they become widespread, reducing the need for broad chemical treatment.

Pheromone Formulation and Release Technologies

Field performance depends on delivering the correct pheromone blend at an appropriate release rate for a sufficient period. Common dispenser designs include rubber septa, polymeric matrices, fibres, flakes, microcapsules and other controlled-release materials. The goal is to create a predictable emission profile under changing temperature and environmental conditions. A dispenser that releases pheromone too rapidly may have a short effective life, whereas a release rate that is too low may fail to produce the desired behavioural response. Advanced formulations therefore attempt to maintain stable release over weeks or months. UV protection, temperature stability and mechanical durability are important for field deployment. Research into microencapsulation, biodegradable carriers and controlled-release materials may improve persistence while reducing the labour required for frequent lure replacement. Such technologies are particularly relevant to mating disruption, where consistent pheromone release over the pest's reproductive period is critical.

Integration with Integrated Pest Management

Pheromone technologies are most effective when integrated into IPM. Monitoring traps can provide an early-warning system, while crop scouting confirms pest density and crop damage. Biological control, resistant cultivars, sanitation, crop rotation, cultural practices and selective insecticides can then be used according to the pest's economic importance. Pheromone monitoring is particularly useful for improving the timing of interventions. Rather than applying insecticides according to a fixed calendar, growers can use trap trends together with crop stage and economic thresholds to determine whether intervention is justified. This can reduce unnecessary applications and potentially slow insecticide resistance. Pheromone-based mating disruption can also complement biological control because it targets reproductive behaviour rather than natural enemies. However, compatibility with other pest-management practices should be evaluated on a crop- and pest-specific basis.

Advantages of Pheromone-Based Technologies

The principal advantage is high target specificity. Many pheromone systems are designed for a single pest species, allowing them to operate with relatively limited direct effects on non-target organisms. They can therefore complement conservation biological control and reduce reliance on broad-spectrum insecticides. Pheromone monitoring also provides quantitative information about pest activity and can be repeated over time. This makes it valuable for forecasting, decision support and evaluation of management interventions. Mating disruption and mass trapping can additionally reduce pest reproduction or adult abundance without requiring uniform treatment of the entire crop surface. Because pheromone-based approaches exploit insect behaviour, they provide modes of action that are fundamentally different from conventional neurotoxic insecticides. This can make them useful components of resistance-management strategies when combined appropriately with other tactics.

Limitations and Challenges

Pheromone technologies are not equally effective for all insect pests. They require a well-characterized and sufficiently strong behavioural response to the target pheromone. Pest density, immigration, landscape configuration, weather and crop structure can all influence efficacy. Mating disruption may be less reliable when pest populations are already very high because more males may successfully encounter females before disruption is sufficient. Small treated areas can also experience immigration from untreated surroundings. These limitations make area-wide coordination particularly important for highly mobile pests. Trap counts are also not direct measures of crop damage. A high catch does not necessarily translate into economic injury, and a low catch does not always guarantee absence of damaging immature stages. Trap data must therefore be calibrated against pest abundance, crop phenology and economic thresholds. Cost, lure longevity and labour for deployment and maintenance can affect adoption. Farmers need clear recommendations on trap density, lure replacement, placement height, timing and interpretation. Extension support and demonstration trials can help translate pheromone technology into practical field use.

Environmental and Climate Considerations

Environmental conditions influence pheromone release, plume movement and insect activity. Temperature affects volatilization and insect behaviour, while wind determines the shape and stability of pheromone plumes. Rainfall, canopy density and atmospheric conditions can further influence trap performance and mating disruption. Climate change may modify pest phenology and geographical distribution, potentially changing the timing and duration of pheromone-based interventions. Earlier pest emergence, additional generations and altered movement patterns could require revised monitoring schedules and longer deployment periods. Climate-aware pest forecasting can therefore improve the timing of pheromone applications. Future field evaluations should test pheromone technologies under realistic combinations of temperature, humidity, wind, rainfall and crop growth rather than relying exclusively on controlled laboratory conditions.

Economic and Farmer Adoption Considerations

Economic feasibility depends on the cost of lures or dispensers, trap density, replacement frequency, labour, crop value and the number of insecticide applications avoided. Mating disruption may require a relatively high initial investment but can provide benefits over several weeks when formulation longevity is adequate. Area-wide programmes can improve economic and biological effectiveness because pests are less likely to immigrate from untreated neighbouring fields. Cooperative approaches among farmers, supported by extension agencies and producer organizations, can therefore be valuable for mobile pests. Technology adoption also depends on simplicity. Monitoring systems should provide clear instructions for trap placement, observation intervals and interpretation of catches. Automated or digital trap systems may reduce labour and improve data quality but should be cost-effective and robust under farm conditions.

Digital and Precision Pheromone Technologies

Recent advances in digital agriculture are creating opportunities to automate pheromone monitoring. Camera-equipped traps can potentially count and classify insects automatically, while wireless sensors can transmit observations to cloud or local decision-support platforms. Such systems can provide near-real-time information on pest activity. Integration of trap data with weather forecasts, crop phenology and spatial information can support pest-risk maps and targeted intervention. Artificial intelligence may assist with automated insect counting, image classification and prediction of population trends. However, field validation is necessary because trap images can contain non-target insects, debris and variable lighting. Precision placement of pheromone dispensers is another emerging opportunity. Spatially variable deployment could concentrate monitoring or disruption resources in areas with high pest pressure, although area-wide approaches remain important where landscape-level movement undermines local control.

Future Perspectives

Future pheromone-based pest management is likely to combine improved semiochemical discovery, synthetic chemistry, controlled-release formulations, automated monitoring and precision agriculture. Identification of new pheromone components and behavioural attractants can expand the range of pests that can be managed through behavioural technologies.

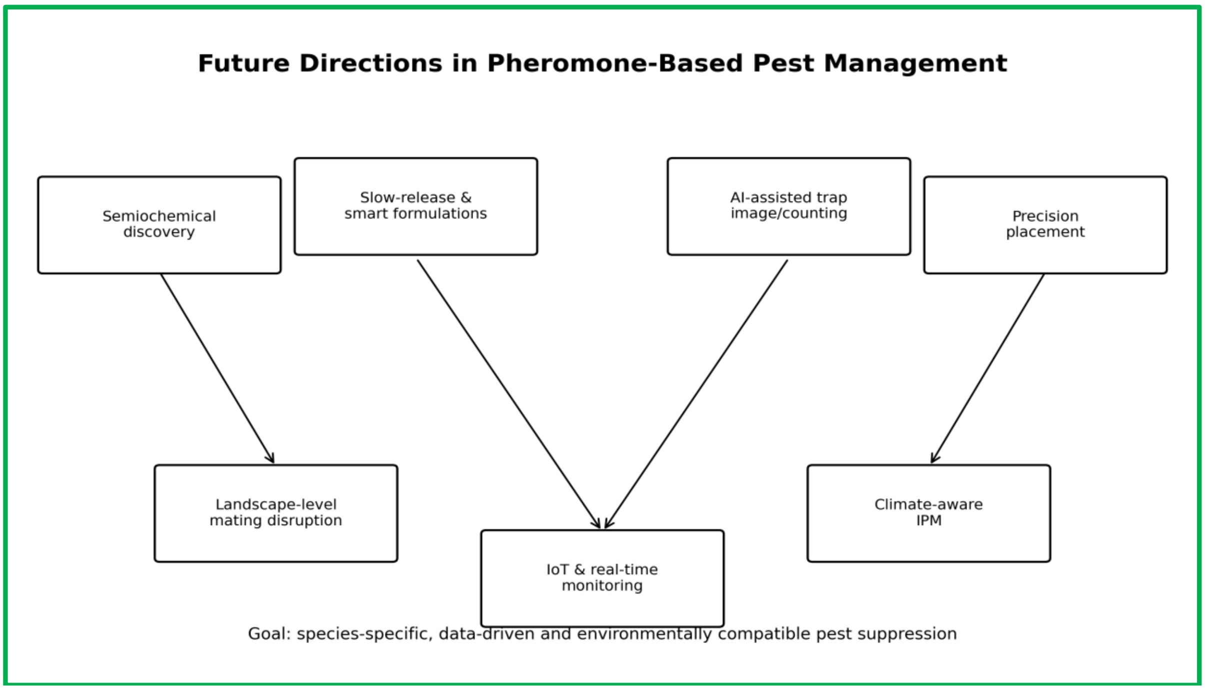

Figure 4. Emerging directions for improving the precision, scalability and sustainability of pheromone-based pest management

Smart dispensers capable of controlled release could improve persistence and reduce the frequency of manual replacement. Biodegradable materials may reduce plastic waste associated with conventional dispensers. Encapsulation and nano- or microstructured delivery systems may also protect pheromones from environmental degradation, although their safety and environmental fate should be carefully evaluated. Area-wide integrated approaches represent an important future direction. Combining pheromone-based mating disruption with mass trapping, biological control, host-plant resistance, sterile insect techniques where appropriate and selective insecticides could provide more durable pest suppression than any single tactic. Climate-informed and data-driven decision support may further improve timing. Trap data, weather conditions and crop phenology can be combined to identify pest-development windows and optimize deployment. The long-term goal is a system in which pheromone technologies function as part of a connected pest-monitoring and decision-making network rather than as isolated traps or dispensers.

Conclusion

Pheromone-based technologies provide a highly targeted approach to agricultural pest management by exploiting insect chemical communication. Monitoring traps, mass trapping, mating disruption and attract-and-kill systems can contribute to early detection, suppression and reduced dependence on broad-spectrum insecticides. Their species specificity and compatibility with IPM make them particularly valuable for sustainable crop protection. The success of these technologies depends on correct understanding of pest biology, adequate deployment scale, formulation performance, environmental conditions and integration with complementary management tactics. Monitoring traps should be interpreted alongside field scouting and economic thresholds, while mating disruption and mass trapping require careful consideration of pest density and immigration. Future progress will depend on advances in semiochemical discovery, controlled-release formulations, automated trapping, artificial intelligence, IoT monitoring and precision agriculture. With appropriate validation, farmer training and area-wide coordination, pheromone technologies can become an increasingly important component of sustainable, low-residue and ecologically compatible agricultural pest management.

References

1. Cardé, R.T. and Minks, A.K. (1995). Control of moth pests by mating disruption: successes and constraints. Annual Review of Entomology, 40: 559–585.
2. El-Sayed, A.M., Suckling, D.M., Wearing, C.H. and Byers, J.A. (2009). Potential of mass trapping for long-term pest management and eradication of invasive species. Journal of Economic Entomology, 102: 815–835.
3. El-Sayed, A.M., Suckling, D.M., Wearing, C.H. and Byers, J.A. (2006). Potential of 'lure and kill' in management of orchard pests. Annual Review of Entomology, 51: 235–262.
4. Welter, S.C., Pickel, C., Millar, J., Cave, F., Van Steenwyk, R.A. and Dunley, J. (2005). Pheromone mating disruption offers selective management options for key pests. California Agriculture, 59: 16–22.
5. Wyatt, T.D. (2014). Pheromones and Animal Behaviour: Communication by Smell and Taste. 2nd ed. Cambridge University Press.
6. Reddy, G.V.P. and Guerrero, A. (2004). Interactions of insect pheromones and plant semiochemicals. Trends in Plant Science, 9: 253–261.
7. Wilson, C. and Lucchi, A. (2006). Semiochemicals for monitoring and management of agricultural insect pests. In: Insect Pheromone Research: New Directions.
8. FAO (2026). Integrated Pest Management. Food and Agriculture Organization of the United Nations.
9. IRAC (2026). Integrated Pest Management and insecticide resistance management principles. Insecticide Resistance Action Committee.