Pheromone-Mediated Mating Disruption for Area Wide Pest Management - Evidence from a Case Study of Cotton Pink Bollworm

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Insects utilize information-carrying molecules known as pheromones for intraspecific communication. These pheromones are essential for mate-finding and reproduction, oviposition, defence, and social organization. It has been found that interfering with pheromone-mediated sexual communication is one of the most benign and sustainable approaches to insect pest management. Consequently, pheromone-mediated mating disruption (MD) has emerged as one of the most innovative pest management strategies. By disrupting chemical communication between male and female insects, this technique suppresses mating and population growth without directly killing the target pest, thereby reducing dependence on conventional insecticides. The success of mating disruption is reflected in its adoption across more than one million hectares worldwide. Success stories have been widely reported in orchard and vineyard production systems, particularly in apple and grape crops, for the management of various lepidopteran moth pests. In annual crops, the area-wide management of cotton pink bollworm through MD technology represents one of the most notable examples of successful pest suppression. Recent advances in pheromone delivery systems, such as passive dispensers, microencapsulated formulations, SPLAT technologies, aerosol puffers, and next-generation biodegradable formulations, are expected to provide significant advancements in transforming area-wide pest management approaches in the near future.

Keywords: *Pheromones, Mating disruption, Dispensers, orchard pests, cotton pink bollworm, Area wide Pest management*

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This chapter provides a comprehensive overview of pheromone-mediated mating disruption against insect pests. It comprehensively discusses the evolution and mechanisms of mating disruption, pheromone formulations and delivery systems used in MD programmes, successful examples of the technology's application against major insect pests, and a case study on the area-wide management of cotton pink bollworm are critically examined.

Introduction

As in other animals, insects use five senses to acquire information from their surroundings. However, insects rely more heavily on chemical cues than most other animals. They utilize chemicals as key signalling molecules to receive and transmit information. These messenger chemicals are commonly referred to as semiochemicals. Semiochemicals play an important role in communication by eliciting physiological or behavioural responses in individuals of the same or different species. When communication occurs between individuals of the same species, the chemicals are called pheromones, whereas chemicals involved in interactions between different species are known as allelochemicals. Pheromones, which are intraspecific semiochemicals, are among the most widely studied compounds involved in insect communication. They play a vital role in regulating the physiology and behaviour of insect pests. Pheromones may have primary roles, such as caste determination in honey bees, or secondary roles such as sex pheromones, aggregation pheromones, and alarm pheromones (Padimi et al., 2023). Among the pheromones, sex pheromones have become more popular for management of insect pests of agriculture horticulture and forestry. These pheromones are being utilized for monitoring, mass trapping and mating disruption of insect pests in species specific manner (Abd El-Ghany, 2020). Pheromone-based technologies are widely utilized in insect pest management, particularly for monitoring and mass trapping, whereas mating disruption (MD) has not achieved comparable levels of adoption (Miller & Gut, 2015). This disparity primarily arises from differences in operational requirements, cost, and ecological constraints.

Monitoring and mass trapping rely on point-source attraction of insects using relatively small quantities of pheromone, making them cost-effective, simple to deploy, and suitable across a wide range of cropping systems and pest densities (Carde & Minks, 1995; Suckling, 2000). However, the use of pheromones MD represents a more advanced and innovative strategy in insect pest management. Unlike conventional approaches that rely on attracting and removing a fraction of the pest population, MD operates by manipulating insect behavior at the population level, preventing successful mating between the male and female insects of target species. This shifts pest control from a reactive to a preventive paradigm. It targets reproduction rather than merely reducing existing populations. It functions at the ecosystem level by permeating the entire crop environment with synthetic pheromones and suppress pest populations over time thus it has potential to employ at relatively large-scale, area-wide integrated pest management programs (Carde, 2021). Considering the importance of this method, the present chapter has included the current state of knowledge and recent breakthroughs in the application of MD for integrated pest management of key insect pests are discussed. Further lessons learnt from many decades of managing cotton pink bollworm thorough mating disruption technology is properly discussed as caste study.

Evolution of Mating Disruption Technique

In general, female insects release certain signalling chemical molecules, known as sex pheromones, to communicate with male insects for mating purposes. Males respond to these signals and follow the chemical pathway to locate the females for mating. Understanding this phenomenon, Adolf Butenandt and his team isolated and identified the first insect sex pheromone, bombykol, from the female silkworm moth, *Bombyx mori* (Butenandt, 1959). This discovery established that insects use specific chemicals for mating communication. Following this discovery, more than 600 lepidopteran pheromones have been identified (Petkevicius et al., 2020). This research led to the utilization of pheromones for monitoring and mass trapping of pests during the 1960s. Sex pheromones have been widely deployed in monitoring and surveillance of pest populations. Different Pheromone lures commercially available for monitoring a wide range of insect pests, especially Lepidopterans, although some are also used for Coleopterans and Dipterans.

Pheromones are also being used as direct control strategy that uses a large number of pheromone traps to reduce the population density of the target species and/or minimize pest damage. Many successful examples can be found in management of key insect pests through mass trapping across the globe (Witzgall, 2010). During the 1960s and 1970s, researchers realized that instead of trapping insects, they could permeate the environment with synthetic pheromones to disrupt chemical communication between the sexes, thereby preventing mating. This idea led to the use of synthetic sex pheromones for direct pest management. The strategy emerged as a reliable tool for use in area-wide programs to control insect pests and manage invasive species. This approach later became widely known as mating disruption technology.

Morton Bereza, a chemist with the U.S. Department of Agriculture, first suggested this idea in 1960. Later, Lyle Gaston and others at the University of California demonstrated that synthetic pheromones could disrupt mating, initially testing the concept on cabbage looper moths in 1967. Harry Shorey and his colleagues at the University of California, Riverside (Gaston et al., 1977), were the first to demonstrate through field trials that the application of formulated synthetic pheromones could control cotton pink bollworm. Eventually, this led to the development of the first mating disruption product, No Mate-PBW®, targeting pink bollworm in cotton, which was introduced by Albany International Company in 1978. These results encouraged researchers to test the approach on a larger scale during the 1980s and 1990s, and it proved successful in orchards, vineyards, and cotton-based production systems.

Mechanism involved in Mating Disruption

The mechanisms of mating disruption are among the most debated and often misunderstood areas in pheromone-based pest management. It is not governed by a single mechanism; rather, multiple processes operate simultaneously. The possible mechanisms involved in mating disruption, as described by Carde (2021), are discussed below.

1. **Competition:** Synthetic pheromone sources compete with females by attracting males to false signals, causing them to waste time and thereby reducing successful mating.
2. **Sensory impairment:** High pheromone concentrations saturate the male sensory system, masking the female signal and preventing males from locating mates.
3. **Camouflage:** A uniform pheromone cloud masks the female signal, making it difficult for males to detect and locate mates.

Pheromone Formulations for Mating Disruption

In monitoring and mass trapping programs, simple and short-lived pheromone lures can effectively attract and capture insects. In contrast, mating disruption requires the establishment of a continuous pheromone cloud throughout the entire field to interfere with mate-finding behaviour. Any gaps or fluctuations in pheromone concentration may allow successful mating to occur. To meet these stringent requirements, considerable research efforts have focused on developing pheromone formulations capable of providing sustained and long-lasting release. Early mating disruption strategies primarily relied on passive dispensers based on polymer reservoirs impregnated with pheromones. Polyethylene tubes, twist ties, and hollow fibres have been widely used by growers for this purpose. However, concerns have been raised regarding the labour-intensive nature of their deployment, as effective mating disruption often requires the placement of 300–1,000 dispensers per hectare, depending on the pheromone release rate, crop canopy structure, and biology of the target pest (Cocco et al., 2013; Ioriatti & Lucchi 2016). Some of the commonly used mating disruption forumations are provided as figures 1-6.

	
Figure 1. Polyethylene Twin-Tube Dispenser	**Figure 2. Polyethylene Tie-Rope Dispenser**
	
Figure 3: Membrane-Sachet Dispenser	**Figure 4: Sprayable Microencapsulated formulation**
	

Figure 5: SPLAT Formulation	Figure 6: Aerosol puffer

Figures (1-6). Different types of mating disruption formulations

To reduce labour requirements and minimize the number of dispensers needed, sprayable microencapsulated formulations were subsequently developed and evaluated under field conditions. These formulations can be applied using conventional spray equipment and generally provide more uniform field coverage. However, their field persistence is relatively limited, typically lasting from a few days to several weeks, thereby necessitating repeated applications in many situations (Knight et al., 2008). Further advancements led to the development of controlled-release technologies such as SPLAT (Specialized Pheromone and Lure Application Technology) and gel-based formulations, in which pheromones are incorporated into wax- or gel-based matrices.

These systems have shown considerable promise owing to their enhanced stability, rain fastness, and extended field persistence (Zada et al., 2009; Srinivas et al., 2021). More recently, aerosol puffers have introduced programmable and timed pheromone release, substantially reducing the number of dispensers required while improving operational efficiency (Benelli et al., 2019). In addition, nanotechnology-based and biodegradable formulations are emerging as promising next-generation alternatives, offering improved protection of pheromone compounds, controlled-release characteristics, and enhanced environmental sustainability (Shangguan et al., 2025).

Successful Examples of Utilizing Mating Disruption Technique

MD has been successfully implemented in a wide range of crops worldwide, although its greatest success has been achieved in perennial fruit crop systems rather than annual crops. Perennial orchards and vineyards provide a favourable environment for maintaining a stable pheromone cloud throughout the season, reducing the immigration of mated females and improving disruption efficiency. Among perennial crops, the most notable successes have been reported in apple, grape, and stone fruit production systems. In annual crops, mating disruption has been applied in cotton, tomato, brinjal, and cole crops. Several commercial formulations are available for managing different target pests, and some important registered products are listed in Table 1.

The success of mating disruption is reflected in its adoption on more than one million hectares worldwide (Gut et al. 2019). Approximately 700,000 hectares of orchards and vineyards are treated annually against three major tortricid pests: codling moth (*Cydia pomonella*), oriental fruit moth (*Grapholita molesta*), and European grapevine moth (*Lobesia botrana*). An additional 75,000 hectares are treated for other tortricid pests, including several leafroller species (Knight et al., 2025). Stone fruits such as peach, nectarine, plum, and apricot have particularly benefited from mating disruption programs targeting oriental fruit moth. Mating disruption has also become a key management strategy for navel orange worm, *Amyelois transitella*, in almond and pistachio production systems, with notable success in California (Higbee et al., 2021).

Table 1: Registered and Commercialized Mating Disruption Products for Important Crop Pests

S.No	Target pest	Target crops	Active ingredient	Formulation type	Product Name	Developed company

1.	Codling moth (*Cydia pomonella*; Tortricidae)	Stone and pome fruits	Blend of (E, E)-8,10-dodecadien-1-ol; (E, E)-8,10-dodecadienal; (E, E)-8,10-dodecadien-1-yl acetate	Vapor release hand held dispenser	Checkmate® CM-XL 2.0	Suterra LLC, USA
				Polyethylene twin-tube dispenser	Iso mate® C TT	Pacific Biocontrol Corporation, USA
				Microencapsulated flowable	CheckMate® CM 2.0 Flowable	Suterra LLC, USA
				Aerosol puffer	Puffer® CM-O Pro	Suterra LLC, USA
				SPLAT	SPLAT CYDIA v2	ISCA Technologies, USA
2.	Oriental fruit moth (*Grapholita molesta*; Tortricidae)	Stone fruits	Blend of (Z)-8-dodecenyl acetate; (E)-8-dodecenyl acetate; (Z)-8-dodecen-1-ol	Polyethylene twin-tube dispenser	Isomate® OFM TT	Pacific Biocontrol Corporation, USA
				Microencapsulated flowable	CheckMate® OFM-F	Suterra LLC, USA
				SPLAT	CheckMate® OFM-SL+	Suterra LLC, USA
3.	European grapevine moth (*Lobesia botrana*; Tortricidae)	Grapevine	(E, Z)-7,9-dodecadienyl acetate	Aerosol Device	Mister Pro	CBC Europe Srl, Italy
				Capsule suspension	LOBESIA PRO SPRAY	M2i Biocontrol, France
				SPLAT	SPLAT Lobesia	ISCA Technologies, USA
4.	Vine mealybug (*Planococcus ficus*; Pseudococcidae)	Grapevine	*Lavandulyl senecioate*	Microencapsulated flowable	CheckMate® VMB-F	Suterra LLC, USA
				Aerosol puffer	Celada™ VMB	Suterra LLC, USA
5.	Navel orange worm (*Amyelois transitella*; Pyralidae)	Nut crops and figs	(Z, Z)-11,13-hexadecadienal	Microencapsulated flowable	CheckMate® NOW-F	Suterra LLC, USA
6.	California red scale (*Aonidiella	Citrus and other fruit crops	(3Z,6R)-3-methyl-6-isopropenyl-	Polythene dispenser	CheckMate® CRS	Suterra LLC, USA

	aurantia; Diaspididae)		9-decen-1-yl acetate			
7.	Pink Bollworm (*Pectinophora gossypiella*; Gelechidae)	Cotton	Z, Z)- and (Z, E)-7,11-hexadecadienyl acetate	Tie Rope	PBKnot	PI ltd, India
			Z, Z)- and (Z, E)-7,11-hexadecadienyl acetate	Gel	Cremit	ATGC, India
			Z, Z)- and (Z, E)-7,11-hexadecadienyl acetate	SPLAT	SPLAT PBW 30 M 1	ISCA Technologies, USA
8.	Diamondback moth (*Plutella xylostella*; Plutellidae)	Crucifers	(Z)-11-hexadecenal	Microencapsulated flowable	CheckMate ® DBM-F	Suterra LLC, USA
9.	Tomato Pinworm (*Keiferia lycopersicella:* Gelechidae*)*	Tomato	(E, Z, Z)-3,8,11-tetradecatrienyl acetate	Microencapsulated flowable	CheckMate ® TPW-F	Suterra LLC, USA
10.	Beet armyworm (*Spodoptera exigua;* Noctuidae*)*	Vegetables	(Z, E)-9,12-tetradecadienyl acetate	Microencapsulated flowable	CheckMate ® BAW-F	Suterra LLC, USA

Beyond lepidopteran pests, vine mealybug, *Planococcus ficus*, represents one of the best examples of successful mating disruption against a non-lepidopteran pest, with widespread adoption in Europe, South America, Israel, and the United States (Daane et al., 2021). In annual crops, significant success has been achieved against pink bollworm, *Pectinophora gossypiella*, particularly in the southwestern United States, Mexico, and India (Staten & Walters, 2021). Mating disruption has also shown considerable promise against tomato pinworm (*Tuta absoluta*), eggplant fruit and shoot borer (*Leucinodes orbonalis),* and diamondback moth (*Plutella xylostella*), although large-scale commercial adoption and evaluation are still limited.

Area Wide Pest Management of Cotton Pink Boll Worm through Mating Disruption Technology (Case Study)

The pink bollworm, *Pectinophora gossypiella* (Saunders) (PBW), is one of the most destructive pests of cotton worldwide, causing significant losses in both yield and fibre quality. Its management with conventional insecticides is challenging because the larvae feed internally within cotton squares and bolls, limiting insecticide exposure. In addition, repeated applications of broad-spectrum insecticides increase production costs and often lead to outbreaks of secondary pests. Consequently, pheromone-based mating disruption has emerged as an effective and environmentally friendly alternative for the management of pink bollworm populations. The pheromone of PBW is commercially known as gossyplure which consists of a 1:1 mixture of (Z, Z)- and (Z, E)-7,11-hexadecadienyl acetates. The hollow-fibre formulation containing the gossyplure (No Mate-PBW®) was registered by Albany International Co., in 1978 (Staten et al., 1987). The results of extensive testing in Arizona and southern California indicated substantial reduction in boll infestations and in the need for chemical insecticides for synthetic pheromone treated fields (Doane & Brooks, 1981). Further, slow-release formulations were also proved effective in managing the pest in United states during early 1980s. One of the earliest mating disruption technologies for pink bollworm was PB-Rope®, a high dose slow releasing formulation, developed by Shin-Etsu Chemical Co., Ltd., Tokyo, Japan. It consists of an 8-inch sealed polyethylene tube reinforced with a wire core and loaded with gossyplure. It was resulted in huge success in United states and Mexico in 1990s (Grefenstette et al., 2009). From then mating disruption has become the most notable tool box in area wide pest management programmes targeting the PBW.

In India evaluations at Dharwad, Karnataka, showed 79–94% reduction in moth catches and 32–41% higher seed cotton yield with PB-Rope technology (Patil et al., 2007). Similarly, Ghauri (2025) also recorded 80% reduction at deployment 250 dispensers per hectare. A mega demonstration, called ‘Project Bandhan was carried out using PBKNOT dispensers in Nagpur district of Maharashtra. Results of this demonstration also revealed that that PBKNOT tied fields reduced the flower damage by 49.2%, boll damage by 58.3% and locule damage by 51.8% averaged over 300 acres in Nagpur district of Maharashtra (Mayee et al., 2023). Field evaluation of Specialized Pheromone and Lure Application Technology for Pink Bollworm (SPLAT-PBW) by Sreenivas et al. (2021) at Raichur, Karnataka, revealed its effectiveness in suppressing pink bollworm infestation. The 500 g $acre^{-1}$ dose recorded the lowest incidence of rosette flowers, green boll damage, and locule damage, at 8.23%, 7.36%, and 8.41%, respectively. This treatment also resulted in a seed cotton yield of 33.59 q ha^{-1}, markedly higher than that obtained under the farmer's standard practice (22.33 q ha^{-1}). Large-scale field studies in Israel (Kehat et al., 1998) Pakistan (Babar et al., 2022; Asif et al., 2025), Egypt (Mohamed et al., 2017) Turkey (Unlu & Mezreli, 2011) demonstrated mating suppression levels exceeding 80–95%, along with substantial reductions in trap catches and crop damage. The success of PB-Rope, twist-tie, and SPLAT formulations demonstrates that area-wide mating disruption is a sustainable and environmentally friendly approach for pink bollworm management, particularly when implemented over large contiguous cotton-growing areas as part of integrated pest management programmes.

Advantages of Mating Disruption

- Reduces insecticide applications and associated selection pressure on target pest populations.
- Exhibits negligible risk of resistance development.
- Ensures residue-free and operator-safe pest management.
- Requires minimal re-entry and pre-harvest restrictions.
- Enhances marketability of low-residue produce.
- Provides highly species-specific pest control.
- Conserves natural enemies and other non-target organisms.
- Compatible with integrated pest management (IPM) systems.
- Promotes environmentally sustainable crop protection.

Limitations of Mating Disruption

- MD programmes, like any other pest management approaches, have inherent limits.

- Requires large, contiguous crop areas (≥2–4 ha) for effective area-wide suppression.
- Dispensers must be deployed before the onset of pest flight and mating activity.
- Most effective under low to moderate pest populations; efficacy declines at high infestation levels.
- Uniform distribution of dispensers is essential to maintain an effective pheromone cloud.
- Immigration of mated females from untreated areas can compromise control.
- Overwintering populations in crop residues may act as sources of reinfestation.
- Temperature and wind can influence pheromone release, dispersion, and persistence.
- Regulatory approval and commercialization may be constrained by extensive registration requirements.
- Successful adoption requires sound knowledge of pest biology, crop phenology, and environmental factors.

Conclusion

Pheromone-mediated mating disruption has emerged as one of the most environmentally benign and species-specific approaches for insect pest management. Its success in perennial fruit crops such as apple, grape, and stone fruits, as well as against cotton pink bollworm in large-scale area-wide programmes, demonstrates its potential. Continuous advancements in pheromone formulations including the passive dispensers, aerosol puffers, SPLAT technologies, and nanotechnology-based delivery systems, are further improving the practicality and effectiveness of this approach. Despite these advantages, several challenges continue to limit wider adoption. Successful implementation requires large contiguous crop areas, timely deployment, low to moderate pest populations, and effective management of pest immigration from untreated areas. High initial costs, labour requirements for some dispenser systems, and regulatory hurdles associated with product registration also remain important constraints. Future research should focus on developing cost-effective, long-lasting formulations, improving application technologies, and integrating mating disruption with other IPM tactics. Addressing these challenges will enhance the scalability and adoption of mating disruption as a key component of sustainable and area-wide pest management programmes.

Conflict of Interest Statement

The authors declare that they have no conflict of interest related to the content of this chapter.

References

Abd El-Ghany, N. M. (2020). Pheromones and chemical communication in insects. In D. Kontogiannatos, A. Kourti, & K. F. Mendes (Eds.), *Pests, weeds and diseases in agricultural crop and animal husbandry production* (pp. 16–30). Intech Open.

Asif, M. U., Muhammad, R., Awais, M., Sohail, M., & Khuhro, N. H. (2025). Management of pink bollworm (*Pectinophora gossypiella*) through mating disruption: An environment-friendly technique. *Pakistan Journal of Zoology*, Advance online publication.

Babar, M. H., Sarwar, G., Khan, A. M. J. E. D., Hameed, A., Mahmood, K., Tauseef, M., & Tabassum, M. I. (2022). Bio-efficacy of PB-Rope (L) as mating disruptant against pink bollworm, *Pectinophora gossypiella* (Saunders) in cotton. *Plant Cell Biotechnology and Molecular Biology, 23*(23–24), 33–42.

Benelli, G., Lucchi, A., Thomson, D., & Ioriatti, C. (2019). Sex pheromone aerosol devices for mating disruption: Challenges for a brighter future. *Insects, 10*(10), 308.

Butenandt, A., Beckmann, R., Stamm, D., & Hecker, E. (1959). The sex attractant of the silkworm moth *Bombyx mori*: Isolation, purification, and determination of structure. *Zeitschrift für Naturforschung B, 14*, 283–284.

Cardé, R. T. (2021). Mating disruption with pheromones for control of moth pests in area-wide management programmes. In J. Koul, A. Cuperus, & N. Elliott (Eds.), *Area-wide integrated pest management* (pp. 779–794). CRC Press.

Cardé, R. T., & Minks, A. K. (1995). Control of moth pests by mating disruption: Successes and constraints. *Annual Review of Entomology, 40*(1), 559–585.

Cocco, A., Deliperi, S., & Delrio, G. (2013). Control of *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) in greenhouse tomato crops using the mating disruption technique. *Journal of Applied Entomology, 137*(1–2), 16–28.

Daane, K. M., Cooper, M. L., Mercer, N. H., Hogg, B. N., Yokota, G. Y., Haviland, D. R., Welter, S. C., Cave, F. E., Sial, A. A., & Boyd, E. A. (2021). Pheromone deployment strategies for mating disruption of a vineyard mealybug. *Journal of Economic Entomology, 114*(6), 2439–2451.

Doane, C. C., & Brooks, T. W. (1981). Research and development of pheromones for insect control with emphasis on the pink bollworm. In E. R. Mitchell (Ed.), *Management of insect pests with semiochemicals: Concepts and practice* (pp. 285–303). Springer.

Gaston, L. K., Kaae, R. S., Shorey, H. H., & Sellers, D. (1977). Controlling the pink bollworm by disrupting sex pheromone communication between adult moths. *Science, 196*(4292), 904–905.

Ghauri, Z. A. (2025). PB Rope dispenser technology for pink bollworm suppression in Punjab cotton. *Ecofriendly, 2*(1), 29–36.

Grefenstette, B., El-Lissy, O., & Staten, R. T. (2009). *Pink bollworm eradication plan in the United States*. United States Department of Agriculture, Animal and Plant Health Inspection Service.

Gut, L. J., Adams, C., Miller, J., McGhee, P., & Thomson, D. (2019). Biological control in integrated management of deciduous fruit insect pests: The use of semiochemicals. In X. Xu & M. Fountain (Eds.), *Integrated management of diseases and insect pests of tree fruit* (pp. 571–662). Burleigh Dodds Science Publishing.

Higbee, B. S., & Burks, C. S. (2021). Individual and additive effects of insecticide and mating disruption in integrated management of navel orangeworm in almonds. *Insects, 12*(2), 188.

Ioriatti, C., & Lucchi, A. (2016). Semiochemical strategies for tortricid moth control in apple orchards and vineyards in Italy. *Journal of Chemical Ecology, 42*(6), 571–583.

Kehat, M., Anshelevich, L., Gordon, D., Harel, M., & Dunkelblum, E. (1998). Evaluation of Shin-Etsu twist-tie rope dispensers by the mating table technique for disrupting mating of the cotton bollworm, *Helicoverpa armigera* (Lepidoptera: Noctuidae), and the pink bollworm, *Pectinophora gossypiella* (Lepidoptera: Gelechiidae). *Bulletin of Entomological Research, 88*(2), 141–148.

Knight, A. L., Larson, T. L., Ketner, K., Hilton, R., & Hawkins, L. (2008). Field evaluations of concentrated spray applications of microencapsulated sex pheromone for codling moth (Lepidoptera: Tortricidae). *Environmental Entomology, 37*(4), 980–989.

Knight, A. L., Preti, M., & Basoalto, E. (2025). What can we learn from dissecting tortricid females about the efficacy of mating disruption programs? *Insects, 16*(3), 248.

Mayee, C. D., Chaudhary, B., Panchbhai, R., Annepu, A. R., & Kapur, R. D. (2023). Mega-field demonstration of management of pink bollworm, *Pectinophora gossypiella*, in rain-fed cotton using mating disruption technology. *Indian Journal of Plant Protection, 50*(4), 115–119.

Miller, J. R., & Gut, L. J. (2015). Mating disruption for the 21st century: Matching technology with mechanism. *Environmental Entomology, 44*(3), 427–453.

Mohamed, H. O., El-Heneidy, A. H., Ali, A. G., & Awad, A. A. (2017). Non-chemical control of the pink and spiny bollworms in cotton fields at Assiut Governorate, Upper Egypt. II. Utilization of the egg parasitoid, *Trichogrammatoidea bactrae*. *Egyptian Journal of Biological Pest Control, 26*, 807–813.

Padimi, V., Manisha, B. L., Singh, S. K., & Mishra, V. K. (2023). Communication in insects: A review. *Journal of Experimental Zoology India, 26*(2), 1317–1327.

Patil, S. B. (2007). *Mating disruption using PB Rope L: A promising option for pink bollworm (Pectinophora gossypiella Saunders) management in cotton*.

Petkevicius, K., Löfstedt, C., & Borodina, I. (2020). Insect sex pheromone production in yeasts and plants. *Current Opinion in Biotechnology, 65*, 259–267.

Shangguan, W., Song, X., Chen, H., Xu, H., Huang, Q., & Cao, L. (2025). How to control the release behavior of insect sex pheromones using nanomicro fiber: Insights from experiment and molecular dynamics simulation. *Journal of Agricultural and Food Chemistry, 73*(22), 13366–13380.

Sreenivas, A. G., Markandeya, G., Harischandra Naik, R., Usha, R., Hanchinal, S. G., & Badariprasad, P. R. (2021). SPLAT-PBW: An eco-friendly, cost-effective mating disruption tool for the management of pink bollworm on cotton. *Crop Protection, 149*, 105784.

Staten, R. T., & Walters, M. L. (2021). Technology used by field managers for pink bollworm eradication with its successful outcome in the United States and Mexico. In J. Koul, A. Cuperus, & N. Elliott (Eds.), *Area-wide integrated pest management* (pp. 51–92). CRC Press.

Staten, R. T., Flint, H. M., Weddle, R. C., Quintero, E., Zariti, R. E., Finnell, C. M., Hernandez, M., & Yamamoto, A. (1987). Pink bollworm (Lepidoptera: Gelechiidae): Large-scale field tests with a high-rate gossyplure formulation. *Journal of Economic Entomology, 80*, 1267–1271.

Suckling, D. M. (2000). Issues affecting the use of pheromones and other semiochemicals in orchards. *Crop Protection, 19*(8–10), 677–683.

Unlu, L., & Mezreli, E. (2011). Control of the pink bollworm *Pectinophora gossypiella* by the mating disruption technique on cotton in a semi-arid region of Turkey. *Phytoparasitica, 39*(1), 19–25.

Witzgall, P., Kirsch, P., & Cork, A. (2010). Sex pheromones and their impact on pest management. *Journal of Chemical Ecology, 36*(1), 80–100.

Zada, A., Falach, L., & Byers, J. A. (2009). Development of sol–gel formulations for slow release of pheromones. *Chemoecology, 19*(1), 37–45.