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Semiochemical-mediated Management of Thrips: Current Advances and Future Prospects

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ABSTRACT

This review synthesized current knowledge on semiochemicals produced by thrips, host plants, and their synthetic analogs, emphasizing their ecological roles and applications in integrated pest management (IPM). Thrips (*Thysanoptera*) were among the most destructive pests of agricultural, horticultural, and ornamental crops worldwide. Their economic impact results from both direct feeding injury and their capacity to transmit tospoviruses, leading to substantial yield losses. Conventional management has relied mainly on chemical insecticides; however, issues such as insecticide resistance, pest resurgence, environmental contamination, and growing consumer demand for residue-free produce have highlighted the urgency for sustainable alternatives. Semiochemicals were behavior-modifying chemicals mediating inter- and intraspecific interactions offered promising opportunities in thrips management. Recent advances have identified aggregation pheromones, plant-derived kairomones, and allomones that could influence thrips behavior. These compounds have been effectively utilized in strategies such as mass trapping, monitoring, and push–pull systems that combine attractants and repellents to manipulate pest movement. Synthetic analogs of natural compounds have further enhanced the stability and field applicability of these tools. Despite their potential, several challenges remained before semiochemical-based management could be widely adopted. These included the need for large-scale field validation, development of cost-effective formulations, optimization of delivery systems, and integration with other pest management tactics within multi-pest frameworks. Future research should focus on understanding species-specific behavioral responses, improving semiochemical blends, and promoting their incorporation into holistic IPM programs. Harnessing these chemical cues could contribute to sustainable, eco-friendly, and economically viable approaches for thrips control.

KEYWORDS: Semiochemicals, thrips, aggregation pheromones, kairomones

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1. INTRODUCTION

Thrips (order *Thysanoptera*) are minute insects, typically less than 1.5 mm long, easily recognized by their elongated, slender bodies, fringed wings, and distinctive asymmetrical piercing–sucking mouthparts. Globally, about 7,700 species have been described, but only 1–2% are considered economically important pests (Mound and Morris, 2007; Sampson et al., 2012). Despite their small proportion, pestiferous thrips exert a disproportionate impact on agriculture due to their wide host range, rapid population growth, and ability to cause both direct and indirect damage. Key pest species such as *Thrips tabaci* (Lindeman), *Frankliniella occidentalis* (Pergande), *Scirtothrips dorsalis* (Hood), and the invasive *Thrips parvispinus* (Karny) have been associated with major yield losses in vegetable, fruit, and ornamental crops across many regions (Kim et al., 2023; Li et al., 2024). Thrips damage crops through two major mechanisms. Direct feeding by adults and larvae involves rasping, puncturing, and sucking cellular fluids from young leaves, flowers, and fruits. This feeding disrupts chlorophyll-containing tissues, leading to leaf silvering, bronzing, distortion, and reduced photosynthetic capacity, which ultimately suppresses plant growth and productivity (Reitz et al., 2020; Li et al., 2024). Even without virus involvement, feeding alone can significantly reduce yields of crops such as chilli, onion, tomato, and capsicum. More critically, thrips are efficient vectors of tospoviruses. Species like *F. occidentalis* and *T. tabaci* transmit Tomato Spotted Wilt Virus (TSWV) and Groundnut Bud Necrosis Virus (GBNV), causing severe epidemics under favorable conditions. The epidemiological significance of thrips–tospovirus interactions, combined with the insects' rapid dispersal and reproductive capacity, has been widely documented (Riley et al., 2011; Rotenberg et al., 2015). For decades, thrips management has depended heavily on repeated applications of synthetic insecticides. Although organophosphates, pyrethroids, neonicotinoids, and spinosyns initially provided reliable control, extensive and prolonged use has selected for resistance across multiple thrips species (Jensen, 2000; Bielza, 2008; Xiu et al., 2024). Rising resistance leads to control failures, greater production costs, and increased reliance on newer chemistries. In addition, frequent insecticide applications disrupt populations of predatory mites, bugs, and parasitoids, resulting in ecological imbalance and potential secondary pest outbreaks. Environmental concerns and shifting consumer preference for residue-free produce further emphasize the drawbacks of pesticide-centric programs (Reitz et al., 2020; Krueger et al., 2016; Diaz et al., 2023). In response to these challenges, behavior-based strategies using semiochemicals have gained attention as promising, environmentally compatible alternatives. Semiochemicals—chemical cues enabling communication within and between organisms include pheromones that mediate intraspecific behaviors such as aggregation and mating, and allelochemicals that structure interspecific interactions. Depending on their ecological function, allelochemicals may act as kairomones, allomones, or synomones (Smart et al., 2014; Dicke and Sabelis, 1988; Li et al., 2024). Understanding how these cues influence thrips behavior creates opportunities for improved management through Integrated Pest Management (IPM). Both plant-derived volatiles and thrips-produced pheromones have shown significant utility in applied settings. Plant volatiles have been incorporated into monitoring traps to enhance attractiveness and improve early detection, allowing timely decision-making (Dicke and Sabelis, 1988; Diaz et al., 2023). Semiochemical-enhanced monitoring helps optimize insecticide use and avoid unnecessary sprays. In addition, aggregation pheromones identified in some species significantly increase trapping efficiency and support mass-trapping programs suitable for open-field and protected cultivation environments (Xia et al., 2025; Li et al., 2022). Repellent or deterrent volatiles also facilitate push–pull strategies, pushing thrips away from main crops while pulling them toward lure-baited traps or trap crops (Xiu et al., 2024; Krueger et al., 2016). Semiochemicals further contribute to biological control by enhancing the foraging efficiency of natural enemies. Synomones released by herbivore-damaged plants can attract predatory mites and bugs, improving natural enemy establishment and their impact on thrips populations (Sadafale et al., 2025a; Thiagarajan and Sachse, 2022; Teulon et al., 2024; Mouden et al., 2017). This review summarizes recent advances in identifying, characterizing, and applying semiochemicals for thrips management. It highlights their ecological roles, outlines progress in plant- and insect-derived semiochemicals, and discusses integration into monitoring, mass trapping, behavioral manipulation, and biological control enhancement. Key challenges include variability in field performance, limited availability of cost-effective formulations, environmental influences on volatile release, and slow adoption among growers. Addressing these constraints will be crucial for incorporating semiochemicals into next-generation, sustainable thrips management programs.

2. SEMIOCHEMICALS AND THEIR ECOLOGICAL ROLES

Semiochemicals are a diverse group of chemical signals that play a vital role in mediating ecological interactions and regulating behavior in both animals and plants. These compounds act as information carriers in natural ecosystems, enabling organisms to detect, interpret, and respond to their surroundings. They function either within species populations, guiding essential biological processes, or across species boundaries, shaping complex interactions such as predation, parasitism, competition, and mutualism. Their specificity and ecological relevance make them of particular interest in pest management, where manipulation of behavior rather than mortality is a promising pathway toward sustainable control strategies.

Broadly, semiochemicals are categorized into two groups depending on the level of communication they mediate. Pheromones are involved in intraspecific signaling. They mediate fundamental activities such as locating mates, aggregating in favorable habitats, dispersing from overcrowded sites, defending territories, or warning conspecifics of danger. For example, aggregation pheromones in thrips can promote group formation on host plants, thereby influencing feeding intensity and oviposition site selection. Alarm pheromones, on the other hand, are typically released under threat and trigger escape or dispersal responses, enhancing individual survival. By orchestrating such behaviors, pheromones maintain coordination within populations and enable species to exploit their ecological niches efficiently.

In contrast, allelochemicals operate in interspecific interactions, creating a chemical dialogue between different organisms. Smart et al. (2014) classified allelochemicals into three subtypes based on the receiver-emitter benefit relationship. Kairomones benefit the receiving organism at the expense of the emitter. For instance, plant volatiles can attract herbivores to a host, aiding insect foraging while resulting in damage to the plant. Similarly, predators and parasitoids often exploit kairomones to locate their prey or hosts. Allomones favor the emitter but disadvantage the receiver. Many plants produce defensive metabolites, such as repellents or deterrents that discourage herbivory. In insects, secretions with defensive or irritating properties act as allomones to ward off natural enemies (Broughton et al., 2015). Synomones act as mutualistic signals, benefiting both emitter and receiver. A key example is Herbivore-Induced Plant Volatiles (HIPVs) released by crops upon thrips feeding. These volatiles can attract predators such as *Orius* species (minute pirate bugs), which feed on thrips, benefiting the plant through reduced pest pressure and the predator through increased prey availability (Dicke and Sabelis, 1988) (Figure 1).

In the context of thrips, semiochemicals influence critical behaviors such as aggregation, host selection, mating and avoidance of natural enemies. For instance, aggregation pheromones produced by males play a key role in the attraction of both sexes, thus increasing mating opportunities and enhancing feeding success (Sadafale et al., 2025b; Hamilton et al., 2005; Kirk and Hamilton, 2004). Plant-derived volatiles often act as kairomones, guiding thrips to suitable hosts, while simultaneously serving as cues for natural enemies such as predatory mites and minute pirate bugs (*Orius* spp.) (Birkett et al., 2004).

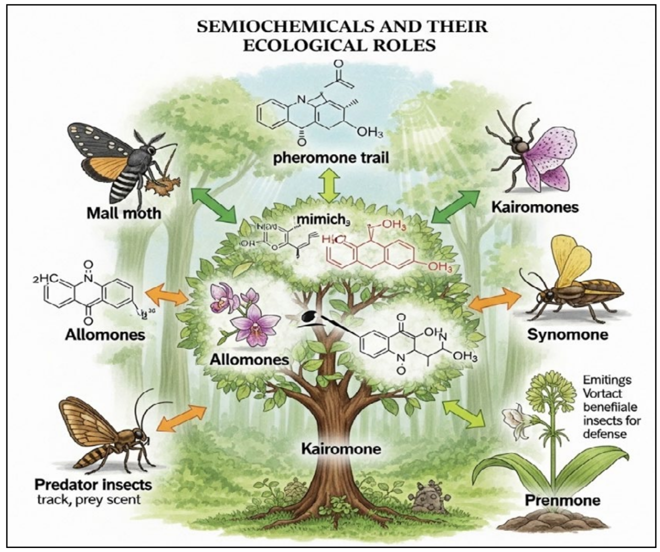

Figure 1: Semiochemicals and their ecological roles

Understanding these ecological roles provides a foundation for developing pest management strategies that exploit thrips chemical communication systems. By either enhancing attractive signals for monitoring and trapping or deploying repellent cues for deterrence, semiochemicals can be integrated into an environmentally sound pest control framework.

3. SEMIOCHEMICALS PRODUCED BY THRIPS

3.1. Aggregation pheromones

Aggregation pheromones represent a key class of semiochemicals actively produced by certain thrips species, playing a central role in shaping their ecology, reproductive success, and population dynamics. In many thrips, these pheromones are synthesized predominantly by males, and their primary ecological function is to attract both conspecific males and females to particular microhabitats. The resulting congregation facilitates mate finding, increases the likelihood of successful copulation, and can promote social aggregation for feeding, oviposition or protection. The chemical nature of thrips aggregation pheromones is typically based on terpenoid esters and monoterpene alcohol compounds renowned for their volatility and biological activity. Importantly, these molecules often exhibit high stereochemical specificity, ensuring effective signal recognition within species and preventing cross-attraction with sympatric thrips.

The western flower thrips, *F. occidentalis*, serves as the model species for aggregation pheromone research. In this species, the primary aggregation pheromone component is neryl (S)-2-methylbutanoate, which is sometimes accompanied by a secondary component, (R)-lavandulyl acetate (Table 1). Studies have demonstrated that the field efficacy and specificity of aggregation lures are influenced not only by the presence of these compounds but by their precise stereochemical configuration and relative ratio (Hamilton et al., 2005; Akella et al., 2014; Broughton et al., 2015). Commercially available aggregation lures are thus typically optimized to include the dominant constituent, ensuring strong and selective attraction of target thrips populations.

Field research highlights that the behavioral response of thrips to aggregation pheromones is further enhanced when deployed in conjunction with visual cues. Sticky traps colored blue or yellow wavelengths to which thrips are innately attracted produce a synergistic effect when combined with pheromonal lures. This dual-modality approach results in a substantial increase in trap catch efficiency, often by 1.5 to 4 times compared to traps employing either cue alone (Davidson et al., 2007; Gómez et al., 2006). Such synergistic integration is now a hallmark of monitoring and mass trapping systems for thrips management.

Recent investigations have revealed daily fluctuations in both the release and composition of aggregation pheromones, suggesting that their biosynthesis and emission are at least partially regulated by circadian rhythms (Hamilton et al., 2005). This regulation may fine-tune aggregation and mating activities to periods of peak environmental suitability or lowest predation risk, conferring adaptive value to the pheromonal signaling system. Understanding these temporal patterns is vital for optimizing lure deployment in the field, as it may dictate the timing of maximum capture success and inform the scheduling of trap servicing (Figure 2).

Recent advances have broadened the understanding of aggregation pheromones beyond *F. occidentalis* to encompass other agriculturally significant thrips species. Investigations

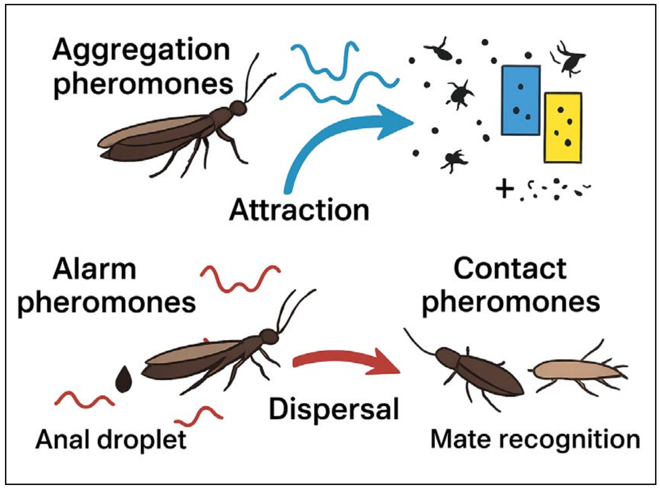

Figure 2: Semiochemicals in Thrips Communication and Management

Table 1: Semiochemical diversity and behavioral functions in thrips

Pheromone Type	Example Species	Chemical Compound(s)	Function	Behavioural Response	References
Aggregation Pheromones	*F. occidentalis*	neryl (S)-2-methylbutanoate, (R)-lavandulyl acetate	Attract both sexes to aggregation	Increased trap catches when combined with visual cues	Hamilton et al., 2005; Akella et al., 2014; Broughton et al., 2015; Gómez et al., 2006.
Contact Pheromones	*F. occidentalis*	7-methyltricosane	Male recognition, mate deterrence	Females reject mating; males display fighting behavior	Olaniran et al., 2013
Antiaphrodisiacs	*Echinothrips americanus*	Dimethyl adipate	Prevent remating of females	Deterrence of other males	Krueger et al., 2016
Alarm Pheromones	Various thrips species	Decyl acetate, dodecyl acetate, perillene	Predator avoidance	Dispersal, increased vigilance, reduced oviposition	de Bruijn et al., 2006; Cook et al., 2002; Blum, 1991
Volatile Mating Pheromones	*F. occidentalis*	Unspecified volatiles	Arrest females during copulation	Enhanced mating	Krueger et al., 2016
Trail-Following Pheromones	Social thrips (Phlaeothripidae)	Hypothesized, unidentified	Coordination of social behaviors	Possible trail following	Kiester and Strates, 1984

into *T. palmi*, *Megalurothrips sjostedti*, and *Dendrothrips minowai* have identified terpenoid esters as the main bioactive constituents of their aggregation pheromones, reinforcing the widespread use of this chemical class within Thysanoptera for intraspecific communication (Xiu et al., 2024; Xia et al., 2025). These findings highlight that the biochemical pathways responsible for pheromone biosynthesis may be conserved across diverse thrips taxa, offering opportunities for broader-spectrum semiochemical applications.

Furthermore, consistent with earlier models, the integration of olfactory signals with appropriate visual stimuli remains crucial for maximizing field attraction efficacy. Blue and yellow sticky traps continue to serve as the preferred visual components, demonstrating additive or even synergistic effects when combined with species-specific aggregation pheromones (Broughton et al., 2015). This multimodal signal deployment is increasingly recognized as essential to achieving practical, scalable monitoring and mass trapping systems in thrips pest management.

3.2. Cuticular hydrocarbons and contact pheromones

Cuticular hydrocarbons (CHCs) constitute a critical class of contact pheromones in thrips, mediating close-range recognition, mating interactions, and social communication. These long-chain hydrocarbons, often ranging from straight-chain alkanes to variously methyl-branched derivatives, form complex chemical signatures on the insect cuticle. In *F. occidentalis*, males produce particularly high levels of 7-methyltricosane, a methyl-branched hydrocarbon that acts as a contact pheromone influencing mate recognition, territorial marking, and deterring rival males (Olaniran et al., 2013). The specific composition and ratios of CHCs vary considerably among thrips species and sexes, providing species- and sex-specific chemical fingerprints that enable individuals to discriminate between conspecifics and potential mates or competitors (Howard and Blomquist, 2005). Through tactile contact or short-range antennal detection, CHCs guide reproductive behaviors in these tiny insects, facilitating mate acceptance or rejection.

3.3. Antiaphrodisiac pheromones

Antiaphrodisiac pheromones represent another nuanced chemical communication strategy in thrips, functioning to reduce female receptivity after mating. In *Echinothrips americanus*, this system is well characterized, with males transferring dimethyl adipate onto females during copulation. This chemical signal deters further mating attempts by other males, effectively ensuring the initial male's paternity by reducing female remating (Krueger et al., 2016). Similar antiaphrodisiac mechanisms are proposed in *F. occidentalis* and potentially other thrips species, although detailed chemical identifications remain limited . By controlling female mating frequency via chemical means, these pheromones contribute to reproductive success and population dynamics and may have unexplored applications in behavioral control.

3.4. Alarm pheromones

Alarm pheromones in thrips are typically volatile acetate esters released through anal droplets upon disturbance or threat. Notable compounds include decyl acetate and dodecyl acetate, which rapidly induce dispersal, increased vigilance, and reduced oviposition behavior among conspecifics (Cook et al., 2002; de Bruijn et al., 2006). Such alarm responses serve as an adaptive group defense mechanism to minimize predation risk and resource competition. Additionally, in some Phlaeothripinae species, the monoterpene perillene has been identified as an alarm pheromone, underscoring chemical diversity in thrips distress signaling (Blum, 1991). Alarm pheromones are gaining traction in integrated pest management, particularly within push–pull strategies designed to manipulate pest distribution patterns and decrease feeding damage in crops (Sadafale et al., 2025c; Diaz et al., 2023; Kim et al., 2023). By repelling thrips from treated areas or driving them toward trap crops, alarm pheromones contribute to environmentally friendly control approaches.

3.5. Other pheromonal signals

Emerging research reveals additional pheromonal signals used by thrips. For example, volatile mating pheromones in *F. occidentalis* have been shown to arrest females during copulation, thereby enhancing mating success. Females of *Echinothrips americanus* produce specific compounds whose pheromonal roles are under ongoing investigation, indicating unexplored chemical communication complexity (Krueger et al., 2016). In social or gregarious thrips, particularly within the family Phlaeothripidae, trail-following pheromones are hypothesized to mediate collective behaviors like coordinated movement and aggregation. While their chemical identities remain largely unknown, behavioral studies support their existence as a social cue critical to group formation and cohesion (Kiester and Strates, 1984; Chown et al., 2021; Li et al., 2024).

4. PLANT DERIVED SEMIOCHEMICALS IN THRIPS MANAGEMENT

4.1. Host plant volatiles and thrips attraction

Plant-derived semiochemicals play a pivotal role in the host location behavior of thrips, which depend extensively on olfactory cues to identify suitable plants for feeding, mating, and oviposition. These volatiles are complex mixtures emitted by flowers, leaves, and other plant parts, providing critical chemical information about plant identity, health status, and physiological condition. Among the myriad volatile organic compounds, terpenoids such as monoterpenes and sesquiterpenes, as well as Green Leaf Volatiles (GLVs), have been identified as particularly influential in eliciting attraction responses from various thrips species.

Several studies has demonstrated that specific plant volatiles can significantly enhance thrips attraction and feeding behavior in both controlled laboratory bioassays and open-field environments. For example, Methyl Isonicotinate (MI), a synthetic analogue of natural plant volatiles, has consistently proven to be a potent attractant for several thrips species, including *F. occidentalis* and *T. tabaci* (Teulon et al., 2014; Davidson et al., 2007). This compound is especially notable because it can increase thrips trap catches by multiple folds compared to unbaited controls, making it a cornerstone in semiochemical-based monitoring tools. Other key volatiles such as linalool, a monoterpene alcohol commonly found in floral scents, and (E)-β-caryophyllene, a sesquiterpene associated with herbivore-induced plant responses, also attract thrips by mimicking cues associated with feeding or reproduction opportunities (Figure 3).

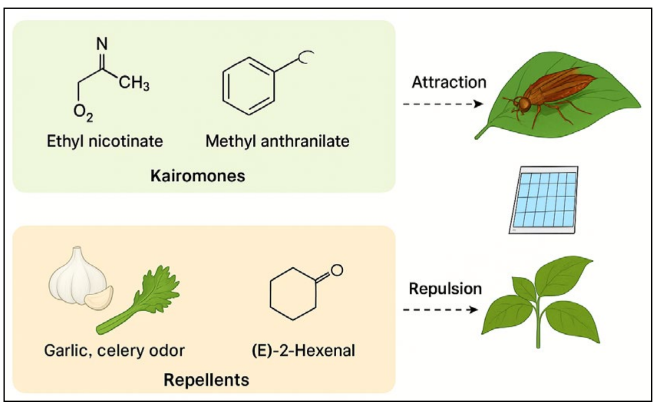

Figure 3: Plant-derived semiochemicals influ encing thrips behavior and their applications in pest management

Integration of these plant volatiles into the design of lure-and-trap systems has revolutionized thrips surveillance and management. When combined with visual stimuli such as blue or yellow sticky traps, which align with thrips' innate phototactic responses, the efficacy of the odor-baited traps is markedly enhanced (Mouden et al., 2017). This multimodal approach leverages both olfactory and visual sensory channels to maximize pest capture, providing growers with more reliable monitoring data and contributing to targeted interventions.

4.2. Non-host volatiles and repellents

Volatiles from non-host plants also play a critical role by acting as repellents or deterrents. For example, essential oil components such as methyl jasmonate and citronellal reduce thrips colonization and feeding (Koschier and Sedy (2003); Koschier et al., 2002, Diaz et al., 2023). Compounds derived from marigold (*Tagetes* spp.) and basil (*Ocimum basilicum*) have shown repellent activity against *F. occidentalis* and *T. palmi*, highlighting their potential for use in push–pull systems (Koschier and Sedy, 2003; Zhang et al., 2011).

4.3. Induced plant volatiles and defense signaling

Plants under herbivore attack often emit Herbivore-Induced Plant Volatiles (HIPVs), which can influence thrips behavior directly or indirectly. Compounds such as (E)-β-ocimene and indole are released upon thrips feeding and can deter conspecifics or attract natural enemies, such as predatory mites and parasitoids (De Kogel et al., 2015; Dicke and Baldwin, 2010). The manipulation of HIPVs represents a promising avenue for enhancing biological control within integrated pest management (IPM).

4.4. Field applications of plant-derived semiochemicals

Plant-derived volatiles have been successfully developed into commercial attractants. Methyl isonicotinate (MI), marketed as *Lurem-TR*, has been widely adopted for thrips monitoring and mass trapping in greenhouse and open-field crops (Teulon et al., 2017; Sampson et al., 2012) (Table 2). When combined with aggregation pheromones or visual stimuli, MI demonstrates synergistic effects, significantly improving trap efficiency (Broughton et al., 2015; Sadafale et al., 2025d; Mouden et al., 2017). Additionally, companion planting with repellent crops such as marigold has been integrated into push–pull systems, effectively reducing thrips densities in vegetable and ornamental crops.

5. MOLECULAR BASIS OF OLFACTION IN THRIPS

Olfaction plays a central role in thrips' survival and reproductive ecology. These tiny insects, despite their small antennal structures compared to larger insects, possess highly specialized chemosensory systems that enable them to locate host plants, conspecific mates, and suitable oviposition sites. Thrips are also vectors of economically important plant viruses, and their ability to detect and discriminate semiochemicals directly influences virus transmission efficiency. Recent advances in genomics, transcriptomics, and electrophysiology have begun to unravel the molecular basis of thrips olfaction, offering promising avenues for pest management through targeted disruption of their chemical communication systems.

5.1. Olfactory receptors (ORs)

Olfactory receptors (ORs) are the primary proteins that mediate volatile odorant detection. In insects, ORs are expressed on the dendritic membranes of olfactory receptor neurons (ORNs) within sensilla located on antennae and maxillary palps. Transcriptome studies in *F. occidentalis* and *T. palmi* have identified dozens of putative OR genes,

Table 2: Plant-derived semiochemicals affecting thrips behavior and ecology

Type	Compound / Source	Target species	Mode of action	Effect on thrips behavior	Plant source	Key references
Attractant / Lure	Ethyl nicotinate	*Thrips obscuratus*	Kairomone	>100-fold increase in trap catches	Synthetic analog (from nicotinic acid)	Davidson et al., 2007
Attractant / Lure	Methyl anthranilate	*Thrips hawaiiensis*	Kairomone	>500-fold increase in trap catches	Present in *Vitis labrusca* (grape), citrus	Imai et al., 2001
Attractant / Lure	Methyl isonicotinate (MI)	Multiple thrips species	Kairomone	Broad-spectrum attraction; commercial lure	Synthetic analog (pyridine derivative)	Davidson et al., 2007; Teulon et al., 2017
Repellent	Garlic, celery odors	*F. occidentalis*	Plant volatiles	Repels thrips from hosts	*Allium sativum* (garlic), Apium graveolens (celery)	Cao et al., 2018
Repellent	(E)-2-Hexenal (cowpea volatiles)	*Megalurothrips sjostedti*	Plant volatiles	Host avoidance	*Vigna unguiculata* (cowpea)	Diabate et al., 2019
Repellent	Rosemary, marjoram, and lemongrass oils	*T. tabaci, M. sjostedti*	Essential oils	Reduced thrips attraction and settling	*Rosmarinus officinalis*, *Origanum majorana*, *Cymbopogon citratus*	Diabate et al., 2019
Deterrent	Acylsugars (tomato hybrids)	*F. occidentalis*	Secondary metabolites	Inhibits oviposition	*Solanum lycopersicum* (tomato) hybrids	Ben-Mahmoud et al., 2018
Deterrent	Flavonoids and phenylpropanoids	Carrot, chrysanthemum thrips pests	Secondary metabolites	Thrips resistance in cultivars	*Daucus carota* (carrot), *Chrysanthemum* spp.	Cheng et al., 2011;
Deterrent	Benzophenanth-ridine alkaloids	Papaveraceae species	Induced metabolites	Post-feeding deterrence	*Papaver* spp. (poppy family)	Schütz et al., 2014
Deterrent	Lavender, marjoram oils	*T. tabaci*	Essential oils	Reduced feeding and oviposition	*Lavandula angustifolia*, *Origanum majorana*	Abtew et al., 2015
Deterrent	Eugenol	*F. occidentalis*	Essential oil component	Delayed feeding and behavioral changes	*Syzygium aromaticum* (clove)	Koschier and Sedy (2003) Abtew et al., 2015
Deterrent	Cis-jasmone, methyl jasmonate	*F. occidentalis*	Jasmonate derivatives	Reduced feeding and oviposition	Common in many plants, esp. *Arabidopsis thaliana, Brassica* spp.	Abtew et al., 2015

many of which show high expression in antennae compared to other tissues (Zhang and Lei, 2015; Li et al., 2022). Functional analysis indicates that these ORs are tuned to terpenoids, green leaf volatiles (GLVs) such as hexenals and hexenols, and specific pheromone components like neryl butanoate. Interestingly, the OR repertoires in thrips appear to be smaller than those of Lepidoptera or Diptera, reflecting their more specialized host range, but the binding specificity is remarkably refined.

5.2. *Ionotropic receptors (IRs)*

Ionotropic receptors (IRs) represent an ancient class of chemosensory receptors derived from ionotropic glutamate receptors. In thrips, IRs are implicated in the detection of amines and organic acids, cues that are critical for identifying stressed or unsuitable hosts. For instance, IRs may mediate responses to acetic acid and other fermentation volatiles released from damaged or decaying tissue (Liu et al., 2021). Such detection mechanisms allow thrips to avoid suboptimal habitats, thereby increasing their ecological fitness. The conserved role of IRs across insect taxa suggests that manipulating these pathways could be a broad-spectrum approach to pest disruption.

5.3. *Gustatory receptors (GRs)*

Although gustatory receptors (GRs) are traditionally associated with non-volatile tastants such as sugars, bitter compounds, and CO_2, they also contribute to thrips' chemical ecology. In *T. palmi*, candidate GRs have been annotated that may detect cuticular hydrocarbons and surface waxes on plants (Mi et al., 2025). These receptors guide short-range behaviors such as probing and oviposition, ensuring that thrips can discriminate between host and non-host species at the point of contact. Moreover, GRs may interact with semiochemicals deposited on plant surfaces, including anti-aphrodisiac pheromones or repellent metabolites, influencing mate choice and site selection.

5.4. *Odorant-binding proteins (OBPs) and chemosensory proteins (CSPs)*

Volatile molecules are generally hydrophobic, posing a challenge for transport across the aqueous sensillum lymph. Odorant-binding proteins (OBPs) and chemosensory proteins (CSPs) fulfill this role by binding odorants and ferrying them to the receptors. In thrips, OBPs have been cloned and functionally assayed, revealing strong affinities to aggregation pheromone components such as neryl (S)-2-methylbutanoate and to kairomones like methyl isonicotinate (MI) (Xia et al., 2025). This suggests that OBPs are finely tuned to ecologically relevant volatiles, amplifying the insects' sensitivity to low-concentration cues. The diversity of OBPs in thrips genomes, though less than in some polyphagous insects, appears sufficient to cover the core range of attractants and repellents encountered in their host environments.

5.5. *Neural integration and sensory processing*

Olfactory receptor neurons (ORNs) housed in antennal sensilla project to the antennal lobe, where signals are integrated before being relayed to higher brain centers such as the mushroom bodies. Electrophysiological studies, including electroantennography (EAG) and gas chromatography–electroantennographic detection (GC-EAD), show that thrips antennal neurons respond robustly to both pheromones and plant-derived kairomones (Thiagarajan and Sachse., 2022). For example, male-produced aggregation pheromones elicit strong excitatory responses in both sexes, while deterrent compounds such as methyl jasmonate suppress neural activity. This highlights a multimodal integration of attractive and repellent signals, allowing thrips to make rapid behavioral decisions in complex odor landscapes.

5.6. *Implications for pest management*

Deciphering the molecular olfactory system of thrips has direct applications for sustainable pest control. By identifying key ORs, IRs, and OBPs responsible for attraction or repulsion, researchers can design synthetic analogues that either lure thrips into traps or block their receptors to impair host-finding ability. RNA interference (RNAi) techniques targeting specific OR or OBP genes have already demonstrated reduced orientation behaviors in thrips (Li et al., 2022). In the future, CRISPR-based gene editing could further clarify receptor function and generate strains for functional validation. Moreover, understanding how thrips integrate pheromone and kairomone signals may lead to multi-component semiochemical blends with superior field performance compared to single compounds.

6. SYNTHETIC SEMIOCHEMICALS AND FIELD APPLICATIONS

6.1. *Development of synthetic attractants*

Identifying natural thrips pheromones and host plant volatiles has paved the way for the development of synthetic attractants that replicate or mimic these bioactive chemicals. Such synthetic analogs and blends have been formulated as standardized lures and deployed in agricultural environments to improve thrips monitoring and control efficacy. The creation of synthetic pheromone lures is particularly significant for *F. occidentalis*, one of the most damaging thrips species worldwide.

Synthetic formulations based on key pheromone components, primarily neryl (S)-2-methylbutanoate and its minor constituent (R)-lavandulyl acetate, have been integrated into slow-release dispensers. These devices provide a controlled and consistent emission of pheromone over extended periods, allowing reliable attraction of *F. occidentalis* adults in greenhouses as well as field conditions (Sadafale et al., 2025e; Hamilton et al., 2005; Akella et al., 2014). The ability to continuously attract both sexes facilitates mass trapping and population monitoring, enabling growers to reduce reliance on chemical insecticides and make informed pest management decisions. Moreover, the stereochemistry and ratio of synthetic pheromone components in these dispensers are optimized to maximize lure specificity and effectiveness.

In parallel, synthetic plant volatile analogs have also been developed into commercial products to exploit thrips olfactory preferences. Methyl isonicotinate (MI), a synthetic compound closely related to natural plant volatiles, has been successfully commercialized under the trade name Lurem-TR. Its use as an attractant across a variety of cropping systems, such as vegetables, flowers, and fruit orchards, has significantly improved the operational feasibility of semiochemical-based trapping systems (Teulon et al., 2014). The consistency of MI release and its potency as a long-range attractant contribute to more effective monitoring and potential reduction of thrips populations through mass trapping.

The development of such synthetic attractants underscores a shift toward more sustainable, behaviorally based pest management strategies. Standardized synthetic lures facilitate easy integration into integrated pest management (IPM) frameworks and allow scalability from smallholder farms to commercial horticulture and large-scale agriculture. Furthermore, ongoing research focuses on optimizing dispenser technologies, improving lure longevity, and blending multiple semiochemicals to target multiple thrips species or life stages. This multi-faceted approach promises to enhance the efficiency and environmental compatibility of thrips control.

6.2. Push-pull systems

Push–pull strategies represent an innovative and ecologically sound approach to thrips management that integrates both repellent and attractant semiochemicals to manipulate pest behavior within agricultural landscapes. This method capitalizes on the behavioral ecology of thrips by using "push" components to repel pests away from the main crop and "pull" components to attract them towards trap crops or lure-baited devices, thereby reducing pest pressure on economically valuable plants. Push–pull systems effectively disrupt pest colonization patterns and feeding activities, while simultaneously minimizing the need for synthetic insecticides, supporting the principles of sustainable integrated pest management (IPM).

A typical push–pull configuration for thrips involves the deployment of attractant-baited traps combined with non-host or companion plants that release repellent volatiles. For example, methyl isonicotinate (MI)-baited sticky traps act as the "pull" factor, drawing thrips such as *T. palmi* and *F. occidentalis* away from crop plants. In parallel, intercrops such as marigold (*Tagetes* spp.) or sweet basil (*Ocimum basilicum*) are strategically planted amidst or around the main crop as "push" components. These companion plants emit volatile organic compounds that thrips find unattractive or repellent, effectively reducing thrips colonization and infestation levels on primary crops like vegetables and ornamentals (Koschier and Sedy, 2003; Zhang et al., 2011).

Experimental and field studies repeatedly demonstrate that such push–pull systems can significantly diminish thrips population densities and associated crop damage. This approach exploits the natural chemical ecology of the pest, leveraging semiochemical cues to steer thrips movement and behavior without harming non-target organisms or beneficial arthropods. Additionally, it fosters biodiversity in cropping systems by supporting companion plants and enhancing habitat complexity, leading to increased populations of natural enemies and improved biological control (Cook et al., 2002) (Figure 4).

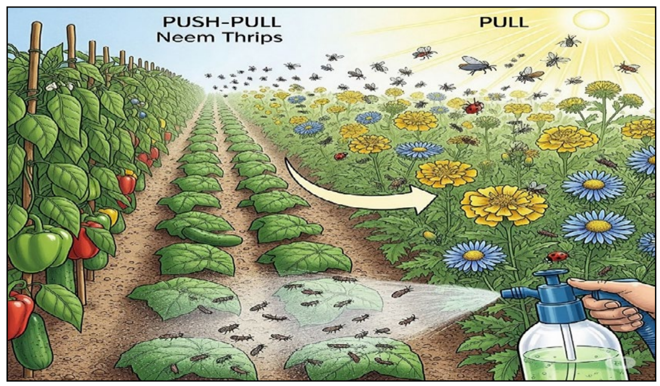

Figure 4: Semiochemicals in push–pull strategy

Modern push–pull strategies often incorporate multiple layers of chemical cues and habitat management to optimize efficacy. For instance, pairing semiochemical repellents with physical barriers or augmentative releases of predators can create synergistic deterrent effects. Such integrative tactics contribute to resilient pest suppression. While challenges remain such as understanding volatile release rates, optimizing spatial arrangements, and ensuring farmer adoption the potential of push–pull systems to reduce insecticide dependency is considerable.

6.3. Mass trapping strategies

Mass trapping has emerged as a powerful semiochemical-based tactic for suppressing thrips populations in various cropping systems. This strategy involves deploying large numbers of traps baited with attractive synthetic semiochemicals to capture and remove substantial proportions of the adult pest population. By significantly reducing the breeding population, mass trapping can lower the overall pest pressure on crops, thereby decreasing damage levels and the need for insecticide applications. Such methods are particularly appealing in high-value crops like vegetables, ornamentals, and fruits, where non-chemical options are preferable.

Recent studies have demonstrated considerable success in combining multiple semiochemical cues to enhance trap efficacy. Notably, the use of thrips aggregation pheromones such as neryl (S)-2-methylbutanoate for *F. occidentalis* in conjunction with synthetic plant volatiles like methyl isonicotinate (MI), results in robust synergistic attraction. Traps baited with this dual lure system achieve two- to threefold increases in trap catches compared to lures containing individual compounds (Broughton et al., 2015; Mouden et al., 2017). This synergy arises because the lures simulate natural multimodal signals that thrips use to identify suitable habitats, thus more effectively intercepting dispersing adults.

The effectiveness of mass trapping strategies is influenced by several critical factors. The release rate of the lures must be carefully calibrated to provide continuous emission at biologically relevant concentrations over the cropping season without rapid depletion or premature degradation. Trap density is another key parameter; insufficient numbers or poorly distributed traps can fail to intercept enough pest individuals to impact population dynamics meaningfully. Crop phenology also influences trapping outcomes as thrips susceptibility and movement behaviors vary with the developmental stages of the host plant. Moreover, the presence of alternative host plants in nearby landscapes can divert thrips away from traps, reducing trapping efficiency (Davidson et al., 2007) (Figure 5).

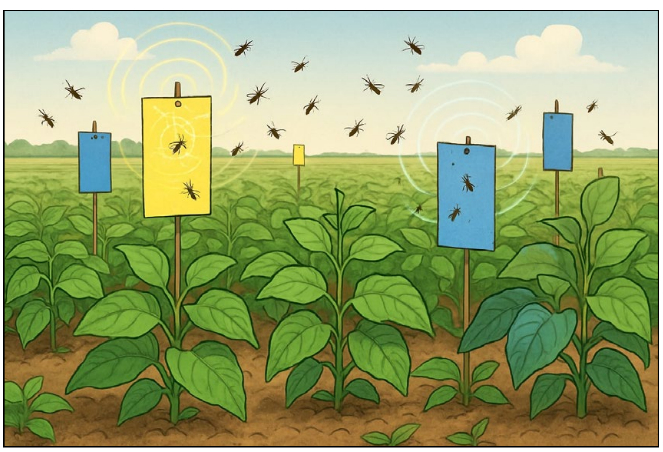

Figure 5: Semiochemicals in mass trapping strategies

6.4. Challenges and limitations

While synthetic semiochemicals hold great promise for sustainable thrips management, their large-scale practical deployment faces several notable challenges and limitations. Environmental factors play a critical role in determining the efficacy and stability of semiochemical lures under field conditions. Temperature fluctuations can accelerate the volatilization and degradation of active compounds, reducing lure longevity and attraction consistency. Wind speed and direction influence the dispersal pattern of semiochemicals, potentially diluting the concentration of attractants or repellents at trap sites and thereby lowering capture rates (Davidson et al., 2007). High humidity and precipitation can also interfere with volatile release or degrade trap adhesives, further complicating the effectiveness of semiochemical-based traps.

Economic feasibility constitutes another significant barrier to widespread adoption, especially in open-field cropping systems with fluctuating and often lower pest pressures than controlled environments such as greenhouses. The cost of synthetic pheromone dispensers or lure formulations, combined with labor requirements for trap installation, monitoring, and servicing, may be prohibitive for smallholder farmers or resource-poor agricultural communities (Sampson et al., 2012). Moreover, the cost-benefit ratio may be unfavorable if pest populations do not reach threshold levels that justify investment in semiochemical technology. Consequently, adoption rates among growers can be inconsistent without clear demonstration of economic returns and user-friendly deployment methods.

7. INTEGRATED APPROACHES FOR SUSTAINABLE MANAGEMENT OF THRIPS

7.1. Monitoring and early detection

Among the various applications of semiochemicals in thrips management, monitoring and early detection have seen the most widespread adoption and greatest practical success. Reliable detection of thrips populations at low densities is crucial for preventing outbreaks and minimizing crop damage in a cost-effective manner. Semiochemical-baited sticky traps have greatly enhanced the sensitivity and specificity of thrips surveillance compared with unbaited traps or visual scouting alone.

Pheromone-and plant volatile-baited traps capitalize on thrips innate olfactory preferences, increasing trap catch rates by targeting adults' natural attraction mechanisms. For instance, traps baited with aggregation pheromones such as neryl (S)-2-methylbutanoate and synthetic plant volatiles like methyl isonicotinate have demonstrated significantly higher catch efficiency for *F. occidentalis* and other pest species under both laboratory and field conditions (Teulon et al., 2014; Sampson et al., 2012). The increased trap sensitivity allows growers to detect thrips presence much earlier than conventional methods, facilitating timely interventions that can prevent population explosions and resultant economic losses.

Monitoring using semiochemical lures supports threshold-based pest management, where insecticide sprays or other control measures are implemented only when pest densities exceed economic injury levels. This approach reduces indiscriminate pesticide use, diminishing environmental contamination and preserving natural enemy communities. Semiochemical traps provide quantitative data on population dynamics and spatial distribution, helping growers make informed decisions on treatment timing and location. Furthermore, ongoing monitoring across seasons and years aids in forecasting pest trends and adapting integrated pest management (IPM) strategies accordingly.

7.2. Enhancing biological control

Semiochemicals are increasingly recognized as valuable tools to enhance biological control strategies within integrated pest management (IPM) frameworks for thrips. By manipulating thrips behavior and spatial distribution, semiochemicals can improve the effectiveness and efficiency of natural enemies, contributing to more sustainable and ecologically balanced pest control.

Aggregation pheromones play a critical role in this context by concentrating thrips populations into confined areas, effectively increasing local pest density. This aggregation facilitates predator foraging by making prey more accessible and easier to locate. For instance, when thrips such as *F. occidentalis* are drawn to pheromone-baited traps or specific plant sites, natural enemies like predatory mites (*Neoseiulus cucumeris*) and minute pirate bugs (*Orius* spp.) demonstrate enhanced predation rates owing to concentrated prey availability (Broughton et al., 2015). Such semiochemical-assisted aggregation can amplify the impact of biological control agents, enabling them to suppress thrips populations more efficiently than in widely dispersed infestations.

7.3. Reducing reliance on insecticides

The widespread and often indiscriminate use of broad-spectrum insecticides has triggered significant challenges in thrips management, foremost among them the development of resistance in key pest species such as *F. occidentalis* and *T. palmi*. This resistance undermines the long-term efficacy of chemical control, forces growers to increase application rates or switch to newer chemistries, and exacerbates environmental and health concerns. In this context, semiochemicals offer promising alternative tools that can reduce reliance on insecticides by enabling behavior-based pest suppression.

Semiochemical-driven tactics such as mass trapping, lure-and-kill, and push–pull systems lower thrips populations proactively and maintain pest densities below economic thresholds, thereby limiting the necessity for frequent or high-dose insecticide applications (Davidson et al., 2007). By capturing or repelling thrips at strategic points in the crop ecosystem, these methods disrupt pest establishment and population growth, diminishing the overall need for chemical interventions. For example, mass trapping with synthetic aggregation pheromones combined with host plant volatiles can intercept dispersing adults, reducing reinfestation rates. Push-pull strategies exploit repellent companion plants alongside pheromone-baited traps to spatially manipulate thrips and prevent crop colonization without harmful chemical inputs. Reduced insecticide usage through semiochemical approaches has multiple ecological and agronomic benefits. Lower pesticide residues on harvested crops improve food safety, addressing consumer demands for healthier produce and regulatory compliance. Preservation of beneficial arthropods such as pollinators and natural enemies is another important outcome, as broad-spectrum insecticides often decimate these populations, leading to secondary pest outbreaks and ecosystem imbalance. Furthermore, minimizing chemical inputs protects soil and water resources from contamination and supports long-term agricultural sustainability.

7.4. Integration with other tactics

For semiochemical-based approaches to achieve maximum effectiveness, they must be integrated as components of a comprehensive, multi-faceted integrated pest management (IPM) program rather than deployed as stand-alone tools. The complex biology and ecology of thrips characterized by continuous infestation pressures in tropical and subtropical regions, a broad polyphagous host range, and rapid generation times-necessitate a multi-layered defense strategy that combines diverse control measures targeting different pest life stages and behaviors.

Cultural practices such as crop rotation and intercropping serve as foundational tactics within integrated thrips management programs. These practices alter the spatial and temporal availability of hosts, disrupt pest life cycles, and can reduce overall thrips build-up in fields. When combined with semiochemical lures or repellents, cultural methods can enhance spatial manipulation of thrips populations. For example, introducing repellent intercrops alongside attractant-baited traps in push-pull systems exemplifies the practical application of combining cultural and semiochemical tools to steer pest movement and reduce crop colonization (Mouden et al., 2017; Zhang et al., 2011).

Utilization of resistant or tolerant cultivars further complements semiochemical strategies by providing inherent barriers to thrips feeding and reproduction. Such cultivars may reduce pest population growth rates and associated virus transmission, thereby lessening the intensity and frequency of chemical or semiochemical interventions needed. When resistant cultivars are combined with semiochemical-based monitoring, mass trapping, or push-pull tactics, growers can achieve enhanced suppression effects while minimizing crop damage and economic loss.

Targeted insecticide applications remain essential in certain situations, especially during peak infestation periods or when pest populations threaten yield. However, integration with semiochemicals allows a reduction in pesticide use by enabling more precise timing, location-specific applications, and lower dosages. Semiochemical lure-and-kill devices can sometimes substitute broadcast sprays, aligning insecticide delivery with pest behavior to maximize efficacy and reduce environmental impact.

In regions with continuous thrips pressure and diverse cropping systems, such as tropical and subtropical areas, integration across biological, cultural, genetic, chemical, and behavioral tactics is critical for long-term, sustainable thrips management. This holistic IPM approach mitigates the risks of resistance development, secondary pest outbreaks, and environmental contamination. It also promotes biodiversity and ecosystem resilience, co-benefiting crop productivity and agronomic sustainability.

8. FUTURE PROSPECTS AND RESEARCH NEEDS

The application of semiochemicals for thrips management is still in its developmental phase, with most practical use limited to monitoring. However, recent advances in chemical ecology and formulation technology highlight several promising research directions.

8.1. Discovery of novel semiochemicals

Despite significant advances in identifying aggregation pheromones and plant-derived attractants for major thrips pests like *F. occidentalis* and *T. palmi*, a large number of thrips species remain chemically uncharacterized. Many of these lesser-studied species include polyphagous pests, emerging invasive species, or regionally important taxa whose semiochemical ecology is poorly understood. Expanding research efforts to chemically profile these diverse thrips is essential for the development of precise, species-specific pest management tools that can be tailored to local agroecosystems (Xiu et al., 2024; Xia et al., 2025).

The discovery process for novel semiochemicals has been greatly enhanced by technological advances in analytical chemistry combined with electrophysiological assays. Techniques such as gas chromatography coupled with electroantennographic detection (GC-EAD) enable researchers to directly link chemical compounds in complex odor mixtures with the antennal responses of thrips. This bioassay-guided approach facilitates the identification of semiochemicals that elicit behavioral activity, filtering out irrelevant components from complex extracts (e.g., plant volatiles or insect cuticular extracts).

High-resolution mass spectrometry, including tandem MS and time-of-flight MS, provides detailed molecular information necessary for elucidation of chemical structures. These capabilities accelerate the characterization of novel pheromones, kairomones, allomones, and synomones, including trace-level compounds that might have been overlooked by earlier methods. Additionally, advances in chemical synthesis techniques enable the rapid production of identified compounds and stereoisomers for behavioral assays and lure formulation.

Integrating these advanced tools with field-based behavioral validations is critical to confirm the ecological relevance and practical utility of newly identified semiochemicals. Such interdisciplinary efforts will facilitate the discovery of attractants, repellents, and synergistic blends, broadening semiochemical-based control options across thrips species complexes.

8.2. Improved formulation and delivery systems

One of the major challenges limiting the widespread adoption of synthetic semiochemicals in thrips management is the relatively short-lived effectiveness of current lures under fluctuating environmental conditions. Factors such as high temperatures, wind, rain, and ultraviolet radiation can accelerate the volatilization and degradation of active compounds, reducing lure longevity and field efficacy (Davidson et al., 2007). To address this, research is increasingly focused on the development of advanced formulation and delivery technologies that provide controlled, sustained release of semiochemicals.

Controlled-release dispensers utilizing microencapsulation techniques encapsulate pheromone or volatile molecules within protective polymeric shells. This approach buffers chemical release rates against environmental extremes, prolonging emission over weeks or months. Polymer-based matrices and slow-release devices offer similar benefits, enhancing stability and maintaining biologically relevant concentrations in the field. These innovations improve the consistency and reliability of semiochemical lures and facilitate integration into routine pest management.

Cost-effective, scalable delivery systems are critical, especially for large-scale open-field cropping systems where semiochemical applications have historically lagged behind greenhouse use. Developing user-friendly dispensers with low production costs and simplified deployment will help expand adoption among smallholder and commercial farmers alike. Continued advances in formulation science, coupled with field validation across diverse agroecological settings, will be essential to unlocking the full potential of semiochemicals for sustainable thrips management.

8.3. Synergistic combinations

Maximizing the efficacy of semiochemical-based thrips management requires future research to focus on optimizing synergistic combinations of chemical signals. Particularly promising are blends combining pheromones with kairomones or other plant-derived allelochemicals to enhance behavioral responses such as attraction or repellence. For instance, studies have shown that combining aggregation pheromones with kairomonal volatiles like methyl isonicotinate (MI) achieves significantly higher trap catches than single-compound lures alone, indicating strong synergistic effects (Broughton et al., 2015).

In addition to chemical blends, integration with visual stimuli such as blue or yellow sticky traps has been demonstrated to further increase trap efficiency by engaging multiple sensory modalities of thrips. This multimodal approach exploits the insects' natural behavioral ecology, improving detection and capture rates under field conditions. Continued exploration of such synergistic interactions could lead to the development of novel lure formulations and trap designs that are both more effective and species-specific.

Future research avenues include identifying optimal ratios of pheromone and kairomone components, exploring new semiochemical compounds, and integrating cues that exploit other sensory modalities such as tactile or gustatory signals. Developing scalable, user-friendly systems incorporating these synergistic combinations will be essential for advancing sustainable, behaviorally based thrips control in diverse agricultural systems.

8.4. Integration with emerging IPM tools

Semiochemicals present exciting opportunities for integration with novel and emerging pest management technologies, potentially revolutionizing thrips control approaches. One promising avenue is combining semiochemical-based lures with RNA interference (RNAi)-based sprays, which target specific gene sequences in pests to suppress population growth with high specificity and minimal non-target effects. Semiochemicals could be used to attract thrips to RNAi-treated areas, enhancing delivery efficiency and reducing spray volumes (Diaz et al., 2023).

Endosymbiont-mediated control strategies, involving manipulation of microbial symbionts that influence pest behavior or reproduction, could also synergize with semiochemical cues by exploiting behavioral attraction or repulsion to optimize symbiont dissemination in thrips populations. For example, semiochemical-baited traps could serve as dissemination points for beneficial microbes.

Precision agriculture tools such as automated pest detection systems employing image recognition or sensor technologies could integrate semiochemical lures for more accurate and real-time monitoring of thrips populations. This would enable timely, site-specific interventions, reducing pesticide use while improving pest suppression. Collectively, these integrated approaches combining semiochemicals with cutting-edge biotechnologies and smart farming tools promise to enhance the sustainability and resilience of thrips management, particularly under the accelerating challenges posed by climate change and global pest invasions.

8.5. Socioeconomic considerations

The successful adoption and impact of semiochemical technologies for thrips management depend not only on scientific advances but also on addressing critical socioeconomic factors. Farmer awareness, cost-effectiveness, technology accessibility, and regulatory frameworks all play pivotal roles in determining whether semiochemical-based integrated pest management (IPM) tools achieve widespread use and sustained benefits.

Smallholder farmers, especially in regions of Asia and Africa where thrips cause significant damage to high-value vegetable and ornamental crops, often face substantial economic and informational barriers to adopting pheromone-based technologies (Sampson et al., 2012; Li et al., 2024). The relative cost of synthetic lures, dispensers, and trap systems can be prohibitive for resource-poor farmers, limiting access and application. Furthermore, lack of familiarity with semiochemical concepts and benefits hampers uptake. Without clear demonstrations of economic advantage and easily deployable systems, hesitation and skepticism may prevail.

To overcome these challenges, future research and extension efforts should emphasize participatory approaches that actively involve farmers in testing, adapting, and validating semiochemical technologies under local conditions. Farmer field schools, hands-on training, and demonstration plots have proven effective in bridging knowledge gaps and building confidence in novel pest management tools. Strengthening local capacity ensures technologies are tailored to user needs and constraints. Policy-level support is also essential. Regulatory approval processes must be streamlined for semiochemical products to facilitate timely market entry. Subsidies or incentive schemes could enhance affordability for smallholders. Developing public–private partnerships can mobilize resources for production and distribution at scale.

9. CONCLUSION

Semiochemicals had shown great potential as eco-friendly tools for thrips management by exploiting their chemical communication for monitoring and control. Despite limitations in large-scale adoption and compound discovery, integrating these cues with visual traps, precision agriculture, and biocontrol approaches had enhanced their effectiveness. Continued research and farmer-oriented innovations were essential to establish semiochemical-based strategies as a sustainable and integral component of thrips integrated pest management.

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