

GENERAL ARTICLE

The Chemical Language of Fruit Flies and Its Future in Pest Management

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Abstract

The Tephritidae family, commonly known as true fruit flies, encompasses over 5000 species and 500 genera distributed globally. The most economically important species belong to the genera *Zeugodacus*, *Bactrocera*, *Anastrepha*, *Ceratitis*, and *Rhagoletis*. These flies significantly threaten fruit production, causing losses ranging from 10% to 30%. Effective communication in these flies involves the exchange of species- and sex-specific cues. Long-distance communication involves pheromones, which might be emitted by one or both sexes. In contrast, medium-to-short communication involves cuticular hydrocarbons (CHCs) with limited volatility and host marking pheromones (HMPs) deposited on fruits after oviposition. Studying the chemical ecology of fruit flies leads to the development of new methods for effective management. Practical applications of this knowledge include mass trapping, monitoring, and direct population management methods such as lure-and-kill and push-pull strategies, which pave the way for advanced approaches such as the Sterile Insect Technique (SIT). The microbiome-mediated semiochemical emissions open novel breakthroughs for better understanding and eco-friendly management of fruit flies. Recent progress in elucidating the molecular basis of olfaction (odorant-binding proteins and olfactory receptors) and CHCs holds significant potential for advancing artificial olfaction. This progress could drive the creation of novel attractants effective at medium and long ranges. To fully realize this potential, future research must focus on gaining a comprehensive understanding of all semiochemical communication modalities within the target species.

Keywords: Fruit flies, Semiochemicals, Cuticular hydrocarbons, Odorant binding proteins, Reverse chemical ecology

Introduction

Fruit flies belonging to the family Tephritidae are not just a nuisance in the kitchen fruit bowl, but they also represent one of agriculture's most economically significant groups of pests, comprising around 5000 species from 500 genera globally. The most economically important species belong to the genera *Zeugodacus* Hendel, *Bactrocera* Macquart, *Anastrepha* Schiner, *Ceratitis* Macleay, and *Rhagoletis* Loew, causing economic losses ranging from 10-30% (Papadopoulos et al., 2024). What makes this family biologically remarkable, however, is not simply its diversity but

the sophistication of its communication system. Long before humans understood the concept of "chemical signalling", fruit flies had already built an entire social order around it using odour to find mates, claim territory, avoid competition, and warn off rivals. This effective communication in these flies involves the exchange of species- and sex specific cues. Insect semiochemicals are a diverse group of compounds that drive key behavioral and physiological responses by regulating chemical communication. Depending on the relationship between the emitter and receiver, these molecules are classified as either pheromones, which

mediate interactions within a single species, or allelochemicals, which facilitate communication between different species.

In Tephritids, three broad classes dominate the conversations including long-range volatile sex pheromones and aggregation pheromones, host marking pheromones deposited on fruit after egg laying and cuticular hydrocarbons (CHCs) that coat insect body and mediate close-contact recognition (Scolari et al., 2021; Fig. 1). Understanding how these “dialects” work and how it can be intercepted or exploited can play an important role in selecting their best management strategies. For each of these three groups, characterizing the tissues responsible for their production and their chemical identities is crucial for fruit fly management. Furthermore, using analytical, electrophysiological, and behavioral methods to uncover their ecological role directly enhances monitoring strategies.

Three “Chemical Dialects” of Fruit Flies

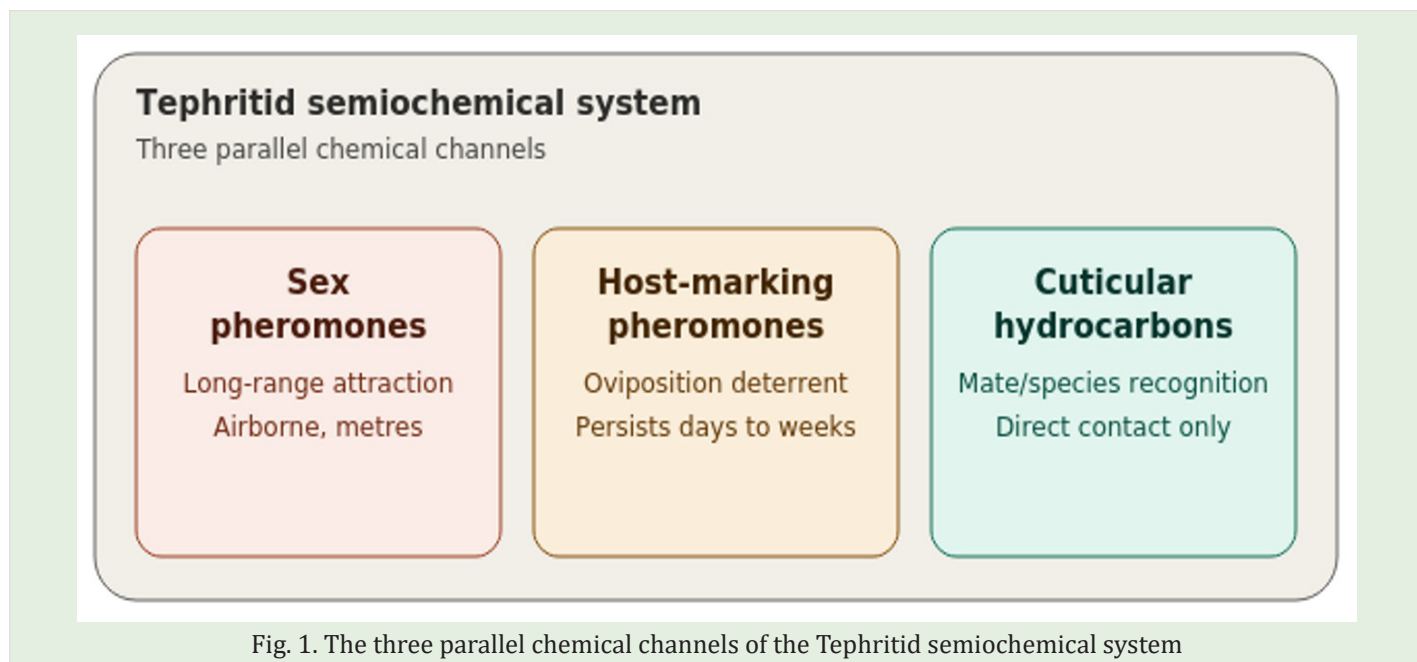
Long-distance sex pheromones are typically airborne and used to locate mates over long distances (Figure 1). Cuticular hydrocarbons (CHCs), by contrast are low-volatile compounds that persist on the body surface or on surfaces

that insect touch and are read only at close range or through direct contact (Fig. 1). Host-marking pheromones (HMPs) occupy a third category entirely: they are not really for “communication” in the conventional sense but a form of chemical memory, deposited on a fruit after oviposition so that other females including the one that laid the eggs can detect it later and avoid re-infesting an already-occupied resource (Scolari et al., 2021; Fig. 1). Together, these three systems shape nearly every major life event in a fruit fly’s existence including courtship, mating, egg-laying and even species recognition.

Choreography of Courtship: Mating Signalling

Reproduction in fruit flies unfolds like a carefully staged chemical drama. Males gather in leks, arenas where they compete purely through sexual signalling, without controlling resources or offering parental care, by performing wing vibration, buzzing, and head rocking to court freely choosing females (Benelli et al., 2014).

Courtship frequently includes trophallaxis, in which males offer oral, genital, or transdermal “gifts.” In *Anastrepha ludens* commonly known



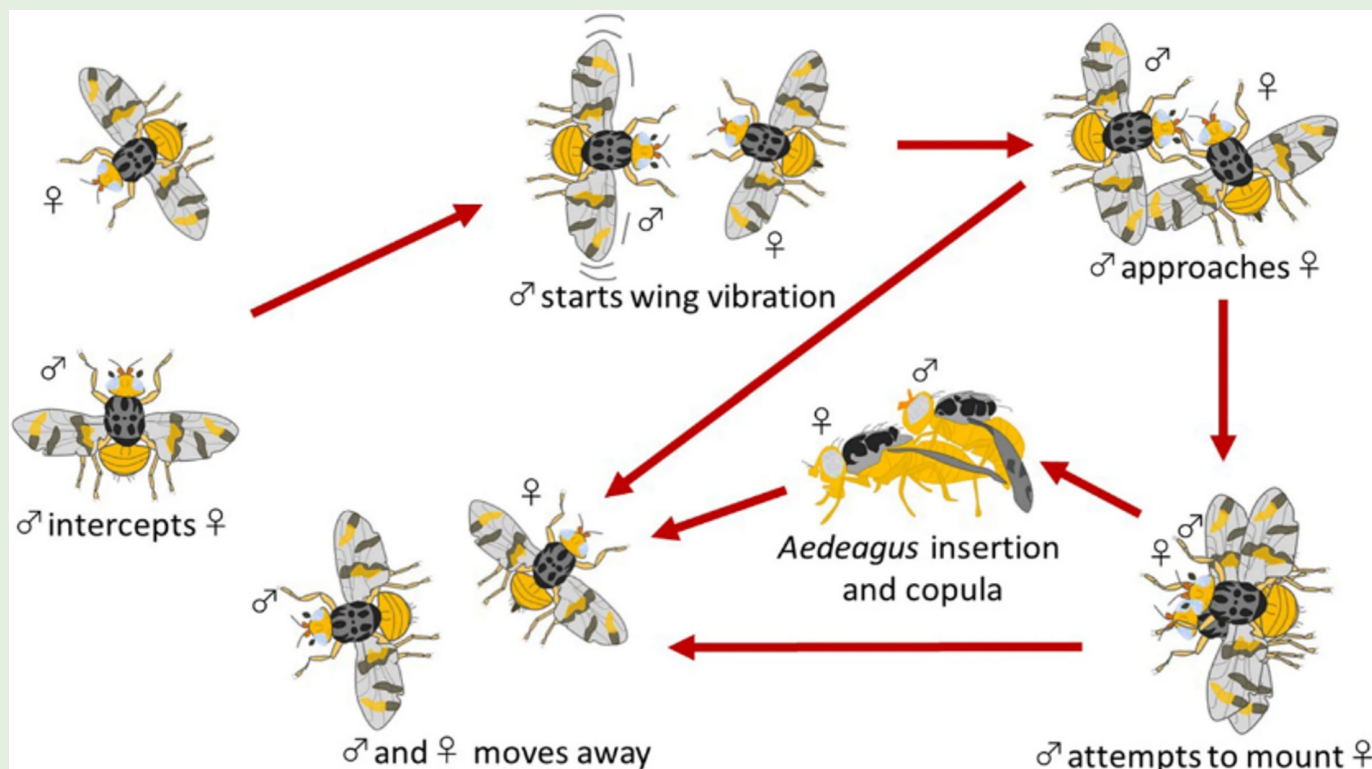
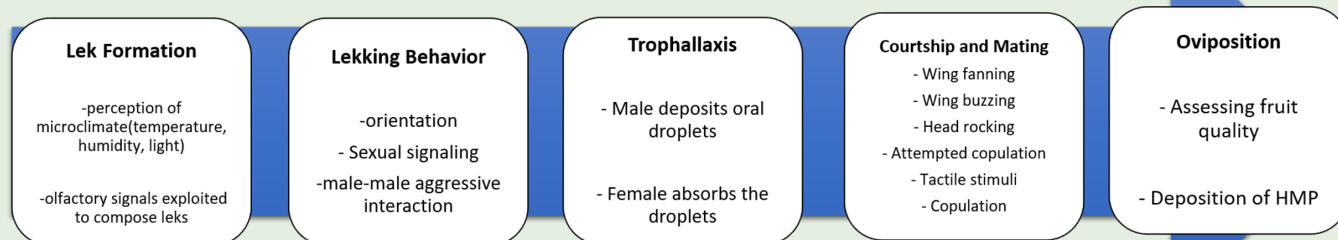


Fig. 2. Role of fruit fly chemicals in courtship

as Mexican fruit fly, males regurgitate more than females, hinting that these secretions may serve multiple roles; from harvesting environmental bacteria and neutralizing ingested toxins to producing oral pheromones (Guillén et al., 2019). As courtship intensifies, volatile chemicals guide long-distance attraction, while less volatile cuticular hydrocarbons take over during close contact, shaping mate acceptance and copulation itself (Clarke, 2019; Fig. 2). Once mated, females undergo a rapid behavioral switch, abandoning pheromone-driven mate-seeking for host-plant cues, and rely on mechanoreceptors, hygroreceptors and gustatory

receptors on the ovipositor to make highly species-specific, context-sensitive oviposition decisions (Leal & Zucoloto, 2008).

From Signal to Strategy: Semiochemicals in Integrated Pest Management

Monitoring of Tephritid Population and Early Outbreak Detection

Early detection of small pest populations is critical for delimiting outbreaks and implementing eradication measures while densities remain low. Highly effective attractants (Table 1) are therefore essential for adult trapping, a primary tool used

to (a) monitor the density and seasonality of established tephritid populations, (b) detect new exotic infestations, and (c) map the boundaries of detected outbreaks.

Push and Pull Approaches

A push-pull strategy (Fig. 3) employs a combination of behavior-modifying stimuli to manipulate the distribution and abundance of target insects. Pests are deterred from a protected resource (the “push”) using host-masking stimuli or repellents. Simultaneously, they are lured toward a localized area (the “pull”) using highly attractive stimuli, such as traps, facilitating their subsequent elimination.

Bacterial-Derived Semiochemicals in Fruit Fly Management

An increasingly promising and eco-friendly approach utilizes volatile organic compounds (VOCs) produced by bacteria associated with fruit flies or their parasitoids. Recent findings

demonstrate that parasitoids, such as *Fopius arisanus*, respond to the host-marking pheromones (HMP) of target fruit fly species (Silva et al., 2012), and could pave the way for enhanced biological control strategies. To further improve the capacity of parasitoids to locate and parasitize tephritid pests in the field, intensified research is needed to elucidate the interactions between parasitoids and fruit fly semiochemicals, particularly oviposition-induced volatiles.

Integration of Sterile Insect Technique (SIT) and Male Annihilation Technique (MAT)

SIT campaigns achieve optimal efficacy when pest population densities are suppressed prior to the release of sterile males. Applying the Male Annihilation Technique (MAT), alongside inundative releases of biological control agents, can effectively reduce feral populations, making them ideal precursors to SIT implementation. Furthermore, in *Bactrocera* species, exposing

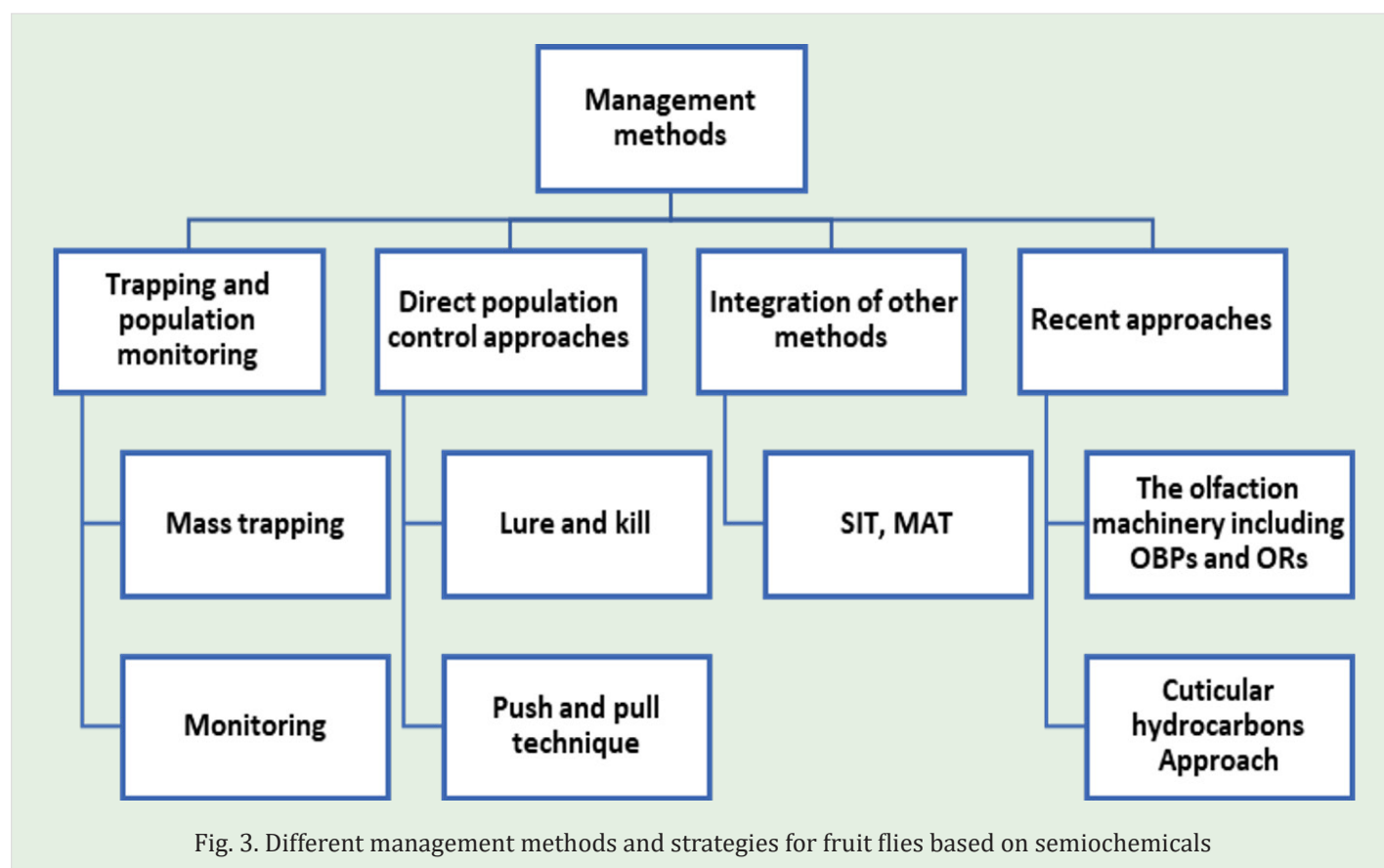


Fig. 3. Different management methods and strategies for fruit flies based on semiochemicals

Table 1. Different attractants used for different Tephritid flies.

Fruit flies	Attractants
<i>Anastrepha</i> spp	McPhail-type traps are standardly baited with torula yeast pellets or a hydrolyzed protein and borax mixture. Additionally, a two-component synthetic attractant consisting of ammonium acetate and putrescine is occasionally deployed in MultiLure traps, a McPhail variant.
<i>Ceratitis capitata</i>	To monitor female <i>C. capitata</i> , McPhail traps are typically baited with torula yeast, hydrolyzed protein with borax, or a three-component dry attractant comprised of ammonium acetate, putrescine, and trimethylamine.
<i>Rhagoletis</i> spp.	Although economically less significant, <i>Rhagoletis</i> spp. are primarily monitored using McPhail-style traps equipped with torula yeast pellets or the hydrolyzed protein and borax blend.
<i>Bactocera</i> spp.	For the detection of <i>B. dorsalis</i> , <i>B. invadens</i> , and <i>B. zonata</i> , traps are equipped with long-lasting methyl eugenol plugs, whereas cuelure is the standard attractant for <i>B. cucurbitae</i> and <i>B. tryoni</i> .

sterile males to plant-derived semiochemicals and synthetic lures before release has been shown to decrease their subsequent response to the attractants used in MAT field applications (Vargas et al., 2010).

Where This Is Heading: Emerging Frontiers

Microbiome-Engineered Rearing

Since gut bacteria are now known to shape both pheromone precursors and cuticular hydrocarbon profiles, deliberately engineering the microbiome of mass-reared flies could become a low-cost way to boost sterile males' mating competitiveness before release.

Reverse Chemical Ecology at Scale

Screening olfactory receptor and binding-protein libraries against candidate compounds, rather than waiting to stumble on them, promises faster discovery of narrowly species-specific attractants and repellents.

Biosensor-Based Surveillance

OBP (Odorant Binding Proteins) -based electronic sensors, still experimental, could eventually flag an incipient outbreak before a single

conventional trap catch anything.

Combined SIT-MAT-Push-Pull Systems

As more cryptic species are resolved through pheromone and CHC chemistry, lure-and-kill, mating disruption, and SIT can all be layered into the same area-wide program with far less collateral impact on non-target insects.

Conclusion

Fruit flies inhabit a chemical universe that is almost entirely invisible to us, a universe of courtship signals, territorial markers, and identity badges written in molecules rather than sound or colour. What began as curiosity about how these insects find mates and avoid competing with their own offspring has, over five decades, matured into one of agriculture's most elegant control strategies. Instead of blanketing orchards with broad-spectrum insecticides, researchers are learning to speak the fly's own chemical language and quietly turn it against the pest itself. As microbiome science, reverse chemical ecology, and nano-sensor technology continue to converge with the semiochemical foundations already in place, the next generation of fruit fly management

looks less like chemical warfare and more like a conversational one, where humans have finally learned enough of the vocabulary to gently redirect.

References

- Benelli, G., Giunti, G., Canale, A., & Messing, R. H. (2014). Lek dynamics and cues evoking mating behavior in tephritid flies infesting soft fruits: Implications for behavior-based control tools. *Applied Entomology and Zoology*, 49(4), 363–373.
- Clarke, A. R. (2019). *Biology and management of Bactrocera and related fruit flies*. CABI.
- Guillén, L., Pascacio-Villafán, C., Stoffolano, J. G., Jr., López-Sánchez, L., Velázquez, O., Rosas-Saito, G., et al. (2019). Structural differences in the digestive tract between females and males could modulate regurgitation behavior in *Anastrepha ludens* (Diptera: Tephritidae). *Journal of Insect Science*, 19(4), 7.
- Gwynne, D., & Bussière, L. (2002). Female mating swarms increase predation risk in a 'role-reversed' dance fly (Diptera: Empididae: *Rhamphomyia longicauda* Loew). *Behaviour*, 139(11–12), 1425–1430.
- Hunter, F. D., & Bussière, L. F. (2019). Comparative evidence supports a role for reproductive allocation in the evolution of female ornament diversity. *Ecological Entomology*, 44(3), 324–332.
- Leal, T. A., & Zucoloto, F. S. (2008). Selection of artificial hosts for oviposition by wild *Anastrepha obliqua* (Macquart) (Diptera, Tephritidae): Influence of adult food and effect of experience. *Revista Brasileira de Entomologia*, 52(4), 467–471.
- Papadopoulos, N. T., De Meyer, M., Terblanche, J. S., & Kriticos, D. J. (2024). Fruit flies: Challenges and opportunities to stem the tide of global invasions. *Annual Review of Entomology*, 69(1), 355–373.
- Scolari, F., Valerio, F., Benelli, G., Papadopoulos, N. T., & Vanickova, L. (2021). Tephritid fruit fly semiochemicals: Current knowledge and future perspectives. *Insects*, 12(5), 408.
- Silva, M. A., Bezerra-Silva, G. C. D., & Mastrangelo, T. (2012). The host marking pheromone application on the management of fruit flies—A review. *Brazilian Archives of Biology and Technology*, 55(6), 835–842.
- Vargas, R. I., Shelly, T. E., Leblanc, L., & Pinero, J. C. (2010). Recent advances in methyl eugenol and cue-lure technologies for fruit fly detection, monitoring, and control in Hawaii. *Vitamins & Hormones*, 83, 575–595.