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Economic Importance of Pheromones in Regulation and Management of Insect Pests in Agricultural Fields

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***Abstract* – Evidence for intraspecific chemical communication in insects is reviewed, with an emphasis on studies involving known organic compounds. These signaling chemicals are known as pheromones. Therefore, this review was aimed at identifying the pheromone types and their significant roles in regulation of insect pest populations. There are two different types of pheromones, triggers and primers. The released pheromones trigger immediate behavioral responses when ingested by insects, while the pheromones trigger physiological changes in the animal that ultimately lead to a behavioral response. There are three main types of chemically identified release pheromones: pheromones that cause sexual attraction, alarm behavior and recruitment. Sex pheromones unleash the entire repertoire of sexual behavior. Thus, male insects can be attracted to an inanimate object that has a sex pheromone and try to mate with it. Most insects appear to be highly sensitive and selective towards the sex pheromones of their own species. Insects show much less sensitivity and chemo specificity to alarm pheromones. Alert selectivity is based more on volatility than on unique structural features. Recruitment pheromones are mainly used to mark paths to food sources. Ground insects create continuous scent trails, while bees and other aerial insects disperse substances at discrete intervals. It appears that the queen bee uses a complex pheromone system to control worker behavior. One established component of this system is the fatty acid 9-ketodecenoic acid, which is produced by the queen and distributed among the workers. This compound prevents the development of worker ovaries and suppresses the reproductive activities of their queens. In addition, virgin bees use the same compound as a sex attractant.**

***Keywords* – Attract, Chemical Communication, Monitor, Pheromone.**

I. Introduction

Pheromones are substances released by a member of a species into the environment that cause a certain reaction in a member of the same species (Hargrave, 2021). Aggregation pheromones produced by males attract males, females, adults and larvae of the same species. This pheromone works over short distances, high concentrations can be repulsive, distance phenomena used by long-lived adult species. Sex pheromones produced by females attract adult males of the same species, act over long distances, and are used by highly mobile, dispersed species and long-lived species.

In insects, these pheromones are detected by antennae on the head. Signals can be effective in attracting distant mates and, in some cases, can be very persistent, remaining stationary and active for days (Conner *et al.*, 1980; Umbers *et al.*, 2015). Long-lasting pheromones make it possible to mark territorial boundaries or food sources. Other signals are very short-lived and aim to convey an immediate message, such as a short-term warning of danger or a short-term readiness to reproduce (Siddiqui *et al.*, 2014; Maslar, 2016). Pheromones can be of different chemical types to perform different functions. Thus, pheromones can range from small hydrophobic molecules to water-soluble peptides.

Long years ago, since the first insect pheromones were identified (Butenandt, 1959; Zhang *et al.*, 2020), there was basic and applied research that led to the amazingly versatile and effective use of pheromones in IPM. Other behavior-modifying semio-chemicals have been less successful at the commercial level, although many studies continue to seek new ways to make host-plant volatiles more useful as attractants or repellents in IPM environments.

Although pheromones are well established in IPM systems, most end users or even applied scientists do not appreciate the work involved in identifying and optimizing pheromone mixtures to be highly species specific and optimally attractive to target species is used in the best way. It usually takes five to ten years of tracking and identification to determine the most effective pheromone mixture formulations and doses for dispensers. Optimizing the trap design for specific species may take several more years. Sometimes, effective pheromones cannot be discovered at all despite decades of intensive effort (Simberloff, 2003; Sullivan and Clarke, 2021). Another obstacle is the delivery of effective commercial products. For example, applied pheromone researchers may spend years determining that a particular mating disruption system is highly effective at damaging crops after conducting experiments in which doses and intensities of disruption dispensers were varied (Benelli *et al*., 2023). An amateur ditto system can work successfully from a biological point of view, but on a commercial level, fail be too expensive or not user-friendly enough compared to standard practices and systems "fail" at this level. It is important to distinguish between failure to trade and biological failure of the mating disruption system itself. Therefore, this review was aimed at identifying the pheromone types and their significant roles in regulation of insect pest populations.

II. Types of Insect Pheromones

2.1. *Sex Pheromones*

The most thoroughly documented cases of long-distance chemical communication are sexual substances used in partner signaling. For example, female butterflies release chemicals into the air to signal their presence and thus attract males over long distances (Regnierand Law, 1968; Hamidi and Frérot, 2020). In one notable case, female monarch butterflies were able to attract males up to 11 km away (Bull *et al*., 1985). Males usually detect females using their antennae. Removing or covering the antennae removes the male's sexual response (Wang *et al*., 991). In 1939, Adolph Butenandt and his colleagues began to isolate and identify an attractant for the commercial silkworm, Bombyxmori. After 20 years of long-term work, 12 mg of derivatives of the compound were extracted from half a million virgins, and in 1959 the active pheromone was identified (Howse *et al*., 2013). Shortly after emerging from the cocoon, the adult female releases the sex pheromone into the air by rotating the abdominal sacs where the compound is formed (Laussmann *et al*., 2022). Males are immediately attracted to the female, where their arousal increases.

2.2. *Alarm Pheromones*

Social animals are the main users of alarm pheromones, alerting other colonies to impending danger. When an alarm signal is received by most animals, their actions are essentially the same. When pheromone concentrations are high, they go crazy and occasionally attack the pheromone source. At low concentrations, they initially osmotically orient to the source (Kumari, 2019). By placing a worker's crushed body close to the nest's entrance, one can easily demonstrate this with ants. Workers typically travel in a few centimeters around one another.

2.3. *Recruitment Pheromones*

Social insects seem to use chemical communication for recruitment; this is demonstrated in termites, ants, and bees (Richard and Hunt, 2013). Among the recruitment pheromones, tracer-marking substances are the most studied. Animals use tracking pheromones as navigational tools to guide other colony members to distant locations, ranging from hundreds of meters for bees to ground insects (Mishra *et al*., 2020). The reasons for sending colonists to a distant point can be different. In most cases, foraging workers create tracks when they return from a food source. These paths are then used by other forest seekers. In other cases, however, opportunities may be created to hire workers to rob slaves, move colonies, or repair a broken beehive wall.

2.4. *Primer Pheromones*

Certain substances have the ability to perform complex functions in certain situations. The function of 9-keto-2-decenoic acid in controlling bee colony behavior is a prime example (Atkins, 1971). Because it is released by the queen and draws the female to the host during mating flights, this compound is classified as a sex pheromone. When mating, mated female insects frequently stop releasing sex pheromones, but queens are an exception to this rule (Regnier and Law, 1968; Bueno *et al*., 2023). When the newly mated queen bee returns to her hive, she continues to produce ketodecenoic acid, which has important inhibitory priming functions.

The bee colony consists mainly of female insects. Drones appear only in summer for breeding; they have no other effect on bee society (Rosenkranz *et al*., 2010). Queen bees can be born from the same fertilized egg as workers. The differences are not genetic; they are born from the special treatment given to the caterpillars of the worker queen. However, under normal conditions there is only one worker queen in the hive, but in summer there can be 30,000 to 80,000 workers. Introducing another fertile or even virgin queen will result in a death match between the queens (Muller and Buchbauer, 2011). When a queen is removed from the hive, workers act quickly to get a new queen. For this purpose, enlarged chambers (queen cells) are built, which are filled with nutrients secreted from the lower jaw (emyol).

III. Uses of Insect Pheromones

3.1. *Monitoring of an Established Population*

There are three main ways to use pheromones in integrated insect pest management. The most important application is monitoring the insect population to determine if they are present or absent in an area or if there are enough insects to require expensive treatment (Dutcher, 2007). This monitoring function is the cornerstone of integrated pest management. The repellent is widely used to control urban cockroach pests, to control pests in grain stored in warehouses or distribution centers, and to control the spread of certain major pests such as gypsy moths, honey fly and Japanese beetles.

Monitoring adult populations of endemic pest species has been the most popular application of pheromones. Initiated in New York State and Michigan in the early 1970s, extensive apple integrated pest management (IPM) programs were founded on effective, species-specific monitoring traps for a variety of moth pests that inflict both direct and indirect harm to trees (Baker, 2009). Leaf roller pest monitoring combined with computerized degree day models (Riedl and Croft, 1974; Riedl *et al*., 1976) allowed spraying to be timed to ensure optimum effectiveness against eggs and primary growth in major pests such as the cod moth (Cydiapomonella) and the oriental fruit moth (Grapholitamolesta). Decisions to spray or not to spray based on the number of adults in trap nets also allowed for effective standardized monitoring traps and operational systems developed against certain pests such as cod moth (Preti *et al*., 2021).

From the mid-1970s to the late 1980s, pesticide use in New York State, Michigan, and the Pacific Northwest decreased by more than 50% due to monitoring programs that improved decision-making about the need for pesticide use and their time (Miller *et al*., 2015). Such programs have been further improved over the years and a concomitant reduction in pesticide use has been documented (Jallow *et al*., 2017). For other crops in the United States and around the world, pheromone control traps have proven to be important factors in the success of these programs in IPM programs. Their use is accepted as an integral and routine part of IPM.

3.2. *Pest Detection and Investigation Program*

Pheromone traps have played an important role in detecting the movement of adult pest species from one area to another and even from non-cultivated areas to cultivated areas. Research programs involving pheromone trap nets are routinely used to report and monitor the early arrival of insects such as the black fly caterpillar (Agrotisipsilon) in the Midwest (Wenninger et al., 2020) or growing populations such as the gypsy moth (Inoue et al., 2019), which have become an integral part of tools for monitoring and mitigating threats from multiple pest movements. One example of the successful use of pheromone traps to identify any invasive species is the pink gorse (Gossectyinopiephora).

3.3. *Mass Trapping*

To eradicate a significant portion of the breeding and feeding population of insects, mass trap insects. In the end, significant decreases in the population density of pest insects contribute to the preservation of resources for human consumption, such as food and fiber. Pine bark beetles have been used in mass trapping experiments, and the results have drawn millions of insects into the traps and away from the trees (Byers *et al*., 2021). Relatives of bark beetles called ambrosia beetles have been mass trapped from log sorting and timber processing areas throughout British Columbia. These trapping operations have reduced damage to the wood in raw logs and newly cut boards.

The previously degraded mass capture technique using either male or female pheromones has recently become a highly valued, highly effective, environmentally friendly and relatively inexpensive means of suppressing populations of certain pest species whose pheromone communication systems and bionomic characteristics make them susceptible to this approach. This technique, after many trials, uses dense traps on crops that have been proven to attract and trap enough insects to reduce crop damage. One example of successful mass capture using pheromone traps is the American palm weevil (Rhynchophoruspalmarum). This species is a very harmful pest of oil and coconut palms in Central and South America. A similar species, *R. ferrugineus*, is a major pest of oil and other palms in the Middle East. Larvae of *R. palmarum* directly damage tree trunks, but they are also vectors of red ring disease; caused by *Rhadinaphe-lenchuscocophilus* (Imrei *et al*., 2020). In the early 1990s, tree losses from either the weevil itself or red ring disease (which requires the removal of infected trees) often reached 15%.

In 1991, after successful initial trials, a large-scale planting of the American palm weevil caught was conducted on two large oil palm plantations in Costa Rica, one 6514 ha and the other 8719 ha (Gonzalez *et al*., 2019). Four bucket traps baited with male sex pheromone and insecticide-treated sugarcane (Gonzalez *et al*., 2019) were placed at chest level at a density of only one trap per two 6. The plants were almost identical. Before the introduction of the mass zone program, standard sanitation measures involving the removal of palms infected with red ring disease were not effective in reducing the incidence of the disease. However, when mass trapping was added to the system, the incidence of diseased trees to be removed decreased from approximately 10,000 diseased trees to 2,000 after one year by almost 80% (Domínguez *et al*., 2022), more than 200000 weevils were caught. In each successive year, the incidence of diseased trees decreased until 2001, only 50 diseased trees had to be sanitary removed (Yuan *et al*., 2021). In the subsequent commercial development of the *R. palmarummassandu* system, it was estimated that there were approximately 25,000 hectares of palm plantations.

Fishing frequency was usually only one fisher per 7 ha. In addition to the ability of this male-based pheromone to attract females, the success of this mass capture system and firstly, it is due to the fact that although weevils are very damaging and cause high tree mortality per bicuria, they are relatively few. Second, weasels have a long adult lifespan, so capturing a moderate number of ewes at a consistent rate throughout the year can eliminate much of the generation and have a significant impact on population growth. Third, adults are strong fliers, which together with a highly attractive pheromone mixture allow pheromone traps to spread over large distances (Dalbon *et al*., 2021). These same features have been used in other very successful and efficient commercial tropical mass capture systems. For *R. ferrugineus*, more than 35,000 hectares of palm plantations are treated annually in the Middle East through mass management. For another palm pest, the coconut horned beetle (Oryctesrhinoceros), more than 50,000 hectares are captured annually in the Middle East. An estimated 10,000 hectares of commercially grown bananas in the American tropics are subject to a mass trapping program each year against the banana borer Cosmopolitessordidus (Germany) (Serra and Lenteren, 2020) was pioneered in the southeastern United States, based largely on the stick bait and trap system developed over many years (Branco *et al*., 2022).

Initially, traps were primarily used as tools for detection and control, and they also helped determine when to spray pesticides. Insecticides would be used if the average number of weevils captured in traps exceeded 0.1 are applied (Telfer *et al*., 2019). On the other hand, mass trapping by itself would be deemed sufficient for population suppression if capture rates were lower than this. In the later years, the traps operated in a mass-trapping mode because populations had been reduced during the preceding years and weevil captures rarely exceeded 0.1 per trap.

3.4. *Mating Disruption*

Mating disorder for agriculturally important moth pests, disruption of mating has been used most effectively in insect populations. In this situation, the synthetic pheromone breaks down on crops, and false scent clouds lure males away from females waiting to mate (Lumini, 2022). This reduces mating and therefore the population density of the pest. In some cases, the effect was so great that pests were locally eradicated. Mating termination involves spreading relatively large amounts of sex pheromones over a hectare of crop and the ability of males to find females to mate with.

Previously, it was assumed that most, if not all, females would have to remain unpaired for pattern interference to be effective, but current thinking has changed, and evidence indicates that female mating efficie-

-ncy only needs to be impaired, that first and second mating are delayed, not prevented. Since the world's first commercial pheromones to disrupt mating against cotton bollworms in 1976, the use of mating disruption technology has grown slowly but steadily (Hendrichs and Robinson, 2021). Globally, nearly 400,000 hectares of various agricultural crops and forests have been subjected to commercial mating disruption in recent years to control various insects (Hendrichs *et al*., 2021). Below are examples of two of the many successful sex termination programs. There are many other examples in the world besides those of the United States.

IV. Conclusion

Pheromone-based techniques for monitoring endemic pest populations, detecting invasive species, suppressing crowding populations, and mating disruption have been relatively recent developments in IPM compared to biological control and insect control techniques. New advances in the use of pheromones in IPM have been made in many areas, including the realization that mass trapping can be a very effective and cost-effective use of these behavior-modifying chemicals. New baits and trapping techniques continue to be developed for new pest species as they appear around the world. It can be summarized as new knowledge is also being gained on how to empirically determine the mode of action of mating-terminating products, and the acceptance of mating-terminating technology by farmers and government agencies has increased in recent years. It remains to be seen whether other behavior-altering chemicals, such as host-plant volatiles, can become as widely used as pheromones in insect IPM in field settings, where pheromones have been an integral part of insect IPM programs.

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