Journal of Plant Protection Research ISSN 1427-4345

REVIEW

Semiochemicals for controlling insect pests

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Vol. 59, No. 1: 1–11, 2019

DOI: 10.24425/jppr.2019.126036

Received: October 3, 2018
Accepted: February 4, 2019

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Abstract

Semiochemicals are defined as informative molecules mainly used in plant-insect or insect-insect interactions as alternative or complementary components to insecticide approaches in different integrated pest management strategies. They are used to manipulate insect behaviour by affecting the survival and/or reproduction of insect pests for controlling their infestations on crops. The present review provides a basic summary of the utilization of semiochemicals for controlling insect pests. Two main topics were explored in this study. The first topic focuses on a description of semiochemicals and their types (pheromones and allelochemicals). Pheromones represent an intraspecific communication amidst members of the same species. Allelochemicals, produced by individuals of one species, modify the behavior of individuals of a different species (i.e. an interspecific effect). Allelochemicals include different informative molecules such as: allomones, kairomones, synomones, antimones and apneumones. The second topic focuses on the application of semiochemicals in IPM programs. Different semiochemicals are included in integrated pest management programs in various ways such as monitoring, mass trapping, attract-and-kill, push-pull, and disruption strategies. Pheromones are promising and can be used singly or in integration with other control strategies for monitoring and controlling insect pests in agricultural systems. For example, sex pheromones have been applied in mass trapping, disruption and attract-and-kill tactics in IPM programs.

Keywords: attract-and-kill, mass trapping, monitoring, push-pull strategy, semiochemicals

Introduction

Semiochemicals are substances or mixtures of substances released from one organism that evokes either a behavioral or physiological response between members of the same or different species. Semiochemicals affect the behavior of insect pests mainly by: insect-insect or plant-insect interactions. Host-plant volatiles provide one or more of four essential resources for the insect: feeding sites, mating sites, egg-laying sites, and/or refugia (Prokopy *et al.* 1984; Witzgall *et al.* 2010). They are considered to be valuable ecologically-friendly strategies for both monitoring and direct control of different insect pests. Chemical communication which occurs between different organisms is divided into two main categories: intraspecific and interspecific, depending on how the interactions occur. Chemical communication is defined as: the emission of a stimulus by one individual which induces a reaction in another one, the reaction being beneficial to the emitter, to the recipient or both (Wilson 1971). Intraspecific communication passes between individuals of the same species, whilst, interspecific communication involves interaction between members of different species. Furthermore, semiochemicals are classified into several functional categories based on the type of signal they communicate and the relation between the receiver and the emitter in the communication channel (Vilela and Della Lucia 2001).

1. Overview of semiochemicals

The classification of the semiochemicals has been described as follows:

1.1. Pheromones: chemical species-specific signals which enable communication between life-forms of the same species i.e. intraspecific communication. Pheromones trigger a reaction in the recipient that causes changes in its behavior (Cork 2004). In 1932, the term "ectohormone" was proposed to describe the chemicals involved in intraspecific interactions (Beth 1932), but the term was replaced by the word pheromone (Gk. phereum, to carry, and horman, to excite or to stimulate) (Karlson and Butenandt 1959; Karlson and Luscher 1959). Subsequently, pheromones have been classified into eight types:

1.1.1. Aggregation pheromones: attract individuals of both sexes at food sites and reproductive habitats. For example, the hemiterpene 3-methylbut-3-en-1-ol has been shown to be the aggregation pheromone for two beetle pests: *Polygraphus rufipennis* Kirby (Coleoptera: Curculionidae) and *Lasconotus intricatus* Kraus (Coleoptera: Zopheridae) (Bowers *et al.* 1991).

1.1.2. Alarm pheromones: alert members of the same species to the presence of a menace. It is considered to be the second most common pheromone produced by insects, after sex pheromones. Some examples are: sesquiterpene (*E*)-β-farnesene (EBF), germacrene A, and α-pinene which were shown to be the main components of the alarm pheromone of several important aphid species (Vandermoten *et al.* 2012).

1.1.3. Oviposition-deterrent pheromones: discourage females from laying eggs in the same resource of another female. Several fruit flies e.g. *Rhagoletis pomonella* Walsh (Diptera: Tephritidae) mark the surface of fruit after oviposition to prevent egg laying by other female flies (Prokopy *et al.* 1982). Interestingly, females of the parasitic wasp, *Diachasma alloeum* (Muesebeck) (Hymenoptera: Braconidae) which attack the maggots of two species of fruit-parasitic flies in the genus *Rhagoletis* lay a single egg in a fly maggot and subsequently deposit a deterrent across the fruit surface by their ovipositor to prevent other females from ovipositing into the marked blueberry, hawthorn, or apple fruit (Stelinski *et al.* 2007).

1.1.4. Home recognition pheromones: there are common in social insect colonies. Bee queens produce a scent-mark to enable workers to recognize her colony. Queen recognition pheromones or more simply "queen pheromones" are exocrine gland products released by the queen that usually attract workers to her, eliciting care and protection. It has been well documented that most queens of social insects have the ability to attract workers. Various glands serve as sources of the queen pheromone, from the mandibular glands in the head of honey bees to the poison sac in the abdomen of fire ants. The queen benefits from the attention of the workers, and the workers may also use the pheromone signal to gain information about the queen. For example, the release of the contents of a poison sac is directly linked to queen egg laying, allowing workers to assess the fecundity of their queen based on the amount of pheromone released into the colony. The honey bee queen pheromone is produced by the mandibular gland and has turned out to be a very complex mixture of compounds. These compounds by themselves are only slightly active but when taken together act as synergists, reproducing the activity from the mandibular gland itself. It is a unique feature of pheromones that most of the compounds are found in tens of micrograms. Even though large quantities of pheromones are produced, the synergistic effects of the components complicate the isolation of the active compounds. No queen pheromones have yet to be isolated and identified from termite species. Only one compound, δ-n-hexadecalactone, has been isolated as a queen pheromone from a wasp species. It was isolated from head extracts and affects worker behavior (Meer and Preston 2008).

1.1.5. Sex pheromones: mediate interaction between sexes of the same species and are mainly produced by females to attract males. The first characterization of a sex pheromone was reported in the silk moth *Bombyx mori* L. (Lepidoptera: Bombycidae) (Butenandt *et al.* 1959). Gossyplure HF (Albany International) was the first registered pheromone product granted by the Environmental Protection Agency (EPA) in February 1978. It was used for the suppression of pink bollworm (Weatherston and Minks 1995). The structure of the majority of known insect pheromones consists of: unbranched aliphatics of nine to eighteen carbons, more than three double bonds, and end with an acetate, alcohol or aldehyde functional group. An example of such a functional group of pheromones is the straight-chained lepidopteran pheromones (SCLPs) (Brossut 1997).

1.1.6. Trail pheromones: guide social insects to distant food sources. Trail pheromones can have both recruitment and orientation effects. Recently, 6-*n*-pentyl-2-pyrone was shown to be the main trail pheromone for the myrmicine ant, *Pristomyrmex pungens* Mayr (Hymenoptera: Formicidae) (McPheron *et al.* 1997).

1.1.7. Recruitment pheromones: induce nestmates to leave the nest and migrate to a work site or vice versa. Recruitment pheromones are discharged from exocrine glands, which are anatomical structures often specialized for synthesis and secretion (Meer and Preston 2008). For example, terrestrial ants have wide glandular sources of recruitment pheromones (Dufour's gland, the pygidial glands, poison glands, sternal glands, hindgut and rectal glands). Pheromones from these sources can be readily seen deposited on a solid substrate. An important model to illustrate the recruitment mechanism is the red fire ant, *Solenopsis invicta* Buren (Hymenoptera: Formicidae). The process begins when a foraging scout worker discovers a food source too large for it to carry back to the colony. The recruitment mechanism includes several sub-categories: (i) initial trail laying by the scout ant, (ii) attraction of additional workers to the scout ant, (iii) induction of the workers to follow the trail and (iv) trail orientation.

1.1.8. Royal pheromones: recently identified from subterranean royal termites as a wax-like hydrocarbon composed of only C and H atoms called "heneicosane". This pheromone enables workers to recognize patronage (kings and queens), thereby maintaining the strain reproductive division (Funaro *et al.* 2018).

1.2. Allelochemicals: substances which transmit chemical messages between different species, known as interspecific communication. Fundamentally, these are substances which are primarily emitted by individuals of one species and are understood by individuals of a different species. They have been divided into five categories: allomones, kairomones, synomones, antimones and apneumones (Vilela and Della Lucia 2001).

1.2.1. Allomones (from Greek "allos + hormone" = excite others): released from one organism that stimulate a response in an individual of another species. The response is beneficial to the emitter, e.g. poisonous allelochemicals. They can also be seen as a deterrent emitted by insects against their predators as a defense mechanism. Granular trichomes which cover plant leaves and stems release herbivore-deterring allomones under stress conditions as a defense process. These allomones are toxic for the herbivorous insect pests, e.g. nicotine from tobacco plant.

1.2.2. Kairomones (from Greek word "kairos" = opportunistic or exploitative): emitted by one organism that stimulate a response in an individual of another species. The response is beneficial to the recipient, e.g. orientation of predaceous checkered beetles (Coleoptera: Cleridae) towards the aggregation pheromone of their prey; bark beetle (Coleoptera: Curculionidae: Scolytinae) (Poland and Borden 1997). Kairomones may be allomones or pheromones depending on the circumstances. For example, American bolas spiders attract their prey (male moths) by releasing attractant allomones which serve as sex pheromones emitted by female moths. Also, exudates of warm-blooded animals that pull blood-sucking insects towards their hosts serve as kairomones.

1.2.3. Synomones: beneficial to both the releaser and receiver. Examples include scents used by flowers to attract pollinating insects. Moreover, herbivore-induced plant volatiles are considered to be active synomones which recruit natural enemies of insect pests towards the affected plant (Turlings *et al.* 1990). Also, synomones play an essential role in mate-finding communication. This role relies on the reduction of competition in the olfaction communication channel between closely related species with overlapping pheromone components. This advisable action is important in preventing exhaustion from the time and energy required for orientation towards heterospecifics (Evenden *et al.* 1999).

1.2.4. Antimones: maladaptive for both the releaser and receiver. These substances produced or acquired by an organism that, when encountered by another individual of a different species in the natural environment, activate in the receiving individual a repellent response to the emitting and receiving individuals.

1.2.5. Apneumones (from Greek word "a-pneum" = = breathless or lifeless): emitted by a non-living source, causing a favorable behavioral or physiological reaction to a receiving organism, but harmful to other species that may be found either in or on the non-living material. Apneumones were suggested by Nordlund and Lewis (1976). Rare cases of these allelochemicals have been found later in the literature e.g. hexanal and 2-methyl-2-butanol released from rabbit stools attracts sandfly females for oviposition (Dougherty *et al.* 1995).

2. Semiochemicals as insect-plant interaction

Phytochemical investigation of plant materials leads to the isolation and identification of different active compounds and explores several activities towards other organism (Hassan *et al.* 2008; Salib *et al.* 2014; Hassan *et al.* 2015; Hassan *et al.* 2016). The wide range of these compounds affects different insect pests in different ways. Herbivorous insects may use these volatiles for determination of food, mates, and/or oviposition and hibernation sites by stimulation of insect chemoreceptor cells in taste sensilla present on antennas, tarsi and mouth parts (Miller and Strickler 1984). The response of insects to plant volatiles differs, and is either attractive (adapted herbivore), or repellent (non-adapted herbivore). Classification of plant volatiles as attractants and repellents is not standardized due to fluctuation of insect behavior responses to such volatiles depending on their concentration.

Some insects develop host plant compounds and use them as sex pheromone precursors or sex pheromones (Reddy and Guerrero 2004). For example, male orchid bees assemble terpenoid mixtures from orchids and transfer them as an aggregation pheromone to stimulate leakage in mating (Dressler 1982). Furthermore, moths, butterflies, grasshoppers, beetles, and aphids utilize pyrrolizidine alkaloids as feeding deterrents against their parasites and/or predators (Nishida 2002).

2.1. Allelochemical classes and their corresponding behavioural or physiological effect on insects

Principal classes of allelochemicals and their corresponding behavioural or physiological effects on insects according to Kogan (1982) are illustrated in Table (1).

2.2. Factors affect insect response to semiochemicals

2.2.1. Semiochemical release rate

Designing an efficient trap is mainly based on the best way of releasing attractive chemicals. The releasing rates in control strategies are considered to be critical for trapping. High release levels of semiochemicals do not actually catch more insects than lower levels. By releasing large quantities, the chemicals may become repellent in the immediate vicinity of the trap. For example, the red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae), responds in different ways to pheromone lure formulations in the laboratory; high release rates of pheromones were neither attractive nor repellent to beetles, whereas old traps were more suitable for use (Hussain *et al.* 1994; Phillips 1994). Thus, optimization of releasing rates could improve performance and efficacy of pheromone traps.

2.2.2. Trap design

Most trapping tactics aim at improving the efficiency of a specific trap rather than information about host-plant volatiles or insect pheromones. There are many factors in trap designing that affect catching efficacy including: shape, size, height, alignment at right angles to the wind, position and timing of the trap. The most commonly used traps for catching insects in the field are sticky, water and inverted cone traps. Sticky traps have been widely developed to kill insects and are used either in mass trapping or in attract-kill tactics. Water traps are unique because they retain insect specimens in good condition. These insects are then suitable for monitoring tactics to detect the entomofauna in a particular area or to estimate fluctuation of a target insect pest (Abd El-Ghany *et al.* 2016). Moreover, a combination of chemical and visual stimuli in trap design is considered to be successful when it affects responses of insects to the same lures (Singer 1986).

Table 1. Principal classes of chemical plant factors (allelochemicals) and the corresponding behavioural or physiological effects on insects

Allelochemical factors	Behavioural or physiological effects
1. Allomones	give adaptive to the producing organism
1.1. Antixenotics	disrupt host selection behaviour
A. Repellents	• orient insect away from plants
B. Locomotory excitants	• start or speed up movement
C. Suppressants	• inhibit biting or piercing
D. Deterrents	• prevent maintenance of feeding or oviposition
1.2. Antibiotics	disrupt normal growth and development of larvae; reduce longevity, and fecundity of adults
2. Kairomones	give adaptive to the producing organism
A. Attractants	• orient insects toward host plant
B. Arrestants	• slowdown or step movement
C. Feeding or oviposition excitants	• elicit biting, piercing or oviposition; promote continuation of feeding

3. Devices used for application of semiochemicals for controlling insect pests

Emission of plums (blend) of semiochemical substances is key to optimizing their effect towards the target insect pest. Controlled-release systems (dispensers) are fundamental to achieving release rates that mimic the natural release. Two main types of devices were recorded for the application of different semiochemical products, retrievable and passive non-retrievable dispensers (EFSA 2016). A description of these devices follows:

3.1. Retrievable dispensers

A – Passive dispensers (extruded or reservoir): the semiochemical substances are continuously emitted into the air.

B – Active dispensers: The semiochemical substance is released discontinuously from the device.

3.2. Passive non-retrievable products

A – Dispensers (biodegradable dispensers): the semiochemical is emitted continuously from the device.

B – Dosable matrix dispensers: the semiochemical is enclosed in a matrix (e.g. sticky polymeric material) onto plants or another substrate at the site of use.

C – Capsule suspension products: the semiochemical is formulated as a microencapsulation (commonly used for pheromone application that allows effective prolongation of releasing levels).

D – Granular products (non-WDG): the semiochemical is formulated in a granular form.

4. Utilization of semiochemicals for controlling insect pests

Recently, semiochemical-based tactics have become an important category of integrated pest management (IPM). Pheromones and other semiochemicals are widely applied not only for controlling insect pests (Weinzierl *et al.* 2005; Cook *et al.* 2007; Stelinski 2007; Heuskin *et al.* 2009), but also for conservation of rare and threatened insects (Larsson 2016). Semiochemicals' efficacy mainly depends on their physical properties i.e. molecular structure, volatility, solubility and lifetime in the environment. Temperature is an important factor that affects the stability (increased diffusion of volatile compounds, leading to decreased molecule lifetime in the environment). There are many advantages of using semiochemicals in IPM strategies such as: their high volatility allows diffusion for long distances, application in low concentrations, and rapid dissipation that reduces health and environmental risks compared with chemical pesticides. For all these reasons, utilization of semiochemical substances provides prospective interest in IPM programs.

4.1. Control strategies using semiochemicals

Various control strategies of insects used in IPM programs are based on semiochemicals and include: monitoring, mass trapping, lure and kill (attract-annihilate), mating disruption, and push-pull strategy (stimulo-deterrent diversion). Pheromones are applied for controlling insect pests in two different ways: indirect control and direct control. Indirect control includes monitoring for quarantine and spray timing strategy, whereas direct control includes mass trapping and area-wide dissemination applications. Area-wide dissemination involves three strategies: disruption, attractant and attract-and-kill (lure and kill) which are widely used commercially. Pheromone traps are used for different purposes in pest management strategies. For example, pheromone-baited traps are used as attracticide or mating disruption techniques to prevent males from reproducing. Additionally, pheromone traps can explore information about the population such as sex ratio and mating status that is useful for determining the population phase which is subject to cyclical changes in population density (Borden *et al.* 2008; Jones and Evenden 2008). Also, pheromones help in measuring the genetic diversity of some insect pests such as the Asian long horned beetle in Asia, North America, and Europe (Carter *et al.* 2009).

4.1.1. Monitoring

Semiochemical-baited traps using pheromones or kairomones are simple, cheap and widely used tools for monitoring different insect pests. These traps are effective for detecting the existence of insect pests, estimating their population density and fluctuation in order to determine the first peak flight activity (Weinzierl *et al.* 2005). Pheromone traps provide an easy, efficient, and extremely sensitive way to detect different insects. Sex pheromones are usually emitted by the female to attract members of the opposite sex (male) for mating. However, aggregation pheromones usually are released from the male and attract members of both sexes resulting in mating and aggregation at a food resource. Rhainds *et al.* (2016) used monitoring strategy for evaluating the abundance of spruce budworm males *Choristoneura fumiferana* Clemens (Lepidoptera: Tortricidae) based on pheromone-baited traps in Canada. Also, this strategy was applied on the lesser date moth *Batrachedra amydraula* Meyrick (Lepidoptera: Batrachedridae) (Levi-Zada *et al.* 2018). In Egypt, many researchers used monitoring strategy for estimating population fluctuations of different insect pests, such as *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) (Abd El-Ghany *et al.* 2016). Moreover, monitoring tactics were applied for detecting the existence of two tomato insect pests: *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) and *T. absoluta* using sticky and water traps, respectively (Abdel-Razek *et al.* 2017; Abd El-Ghany *et al.* 2018).

4.1.2. Mass trapping

Controlling insect pests can be achieved by attracting the target pest to a semiochemical-based lure and subsequent removal of the attracted pest from the wild population. These strategies can be done using mass-trapping or attract and kill tactics. Mass trapping, as a mechanical control strategy, follows the monitoring steps for removing low pest densities of insect pests (Knipling 1979; El-Sayed *et al.* 2006). This tactic is a density dependent technique that eliminates males or females from the pest population, leading to retardation of population growth. A lure is created with sleeves or rubber septa as a substrate for the semiochemical substance fixed on a sticky surface or in liquid holders. Continuous maintenance of this type of trap is required due to saturation with captured insects. Recently, this technique has been an effective management tactic for controlling the Japanese beetle, *Popillia japonica* Newman (Coleoptera: Scarabaeidae) (Piñero and Dudenhoeffer 2018).

4.1.3. Attract and kill

Several pest management strategies employ pheromone-baited or kairomone-baited traps to monitor populations for different purposes. Attract-and-kill is a tactic used for trapping and simultaneously killing the captured pests. This strategy has been applied to insect pests of both field crops and stored products. Studies on the attract-and-kill tactic have been either for long-term pest management of e.g. the Egyptian cotton leafworms, codling moths, biting flies, apple maggots, and bark beetles; or they have been used for eradication of invasive species e.g. boll weevils and tephritid fruit flies (Phillips 1997; Prokopy *et al.* 2000; Stelinski and Liburd 2001; El-Sayed *et al.* 2009). Furthermore, the attractiveness of ammonium carbonate as a general olfactory cue combined with a five-component apple volatile mixture has been used in a red attracticidal sphere system for controlling the apple maggot fly (Morrison *et al.* 2016). For storage facilities, pheromone traps provide information important for making management decisions. Pheromones have been chemically identified from over 35 species of stored-product insect pests, all of which are beetles and moths (Burkholder 1990; Phillips 1994). The most common uses of pheromones for storage pests are as attractant lures in traps to detect the presence of pests and to monitor the activities of pest populations.

4.1.4. Mating disruption

Mating disruption is a strategy which uses species-specific sex pheromones that affect mating behavior by releasing huge amounts of synthetic pheromones into the atmosphere. Application of this tactic was performed with different orchard moths (McDonough *et al.* 1992; Barrett 1995; Atterholt *et al.* 1999; Stelinski 2007; Witzgall *et al.* 2010). Four mechanisms of mating disruption are considered: (i) competitive attraction (false trail following): semiochemical substances draw the attention of the males away from wild females thereby following a false trail, (ii) confusion of males (camouflage): confusion occurs due to saturation of the environment with semiochemical substances causing random flight patterns and thereby missing the female position and effectively blocking mating, (iii) sensory desensitization: adaptation of the male antennal receptor system or habituation of the central nervous system as a neurophysiological effect processing due to overexposure to semiochemical substances (continuous and high background concentration), and finally (iv) disguise (emigration of males prior to mating): males emigrate from the area due to excess pheromone, causing them to be unavailable for mating with virgin females (Barclay and Judd 1995; Mafra-Neto *et al.* 2014).

Mating disruption is used as a potential control for lepidopteran pests. In Canada, Rhainds *et al.* (2012) recommended that the pheromone-based mating disruption tactic be added to the IPM programs for important forest defoliator insect pests such as the spruce budworm using a sprayable commercial pheromone formulation. Also, the disruption strategy has been used to disrupt the aggregation behaviour of some insect species which has led to the reduction of pest populations using heterospecific attractive semiochemical compounds (antiaggregation pheromones and heterospecific synomones). These semiochemicals were used for controlling bark and ambrosia beetles and depended on regulating the attack density by blocking late-arriving beetles from attacking a tree of conspecifics or heterospecifics, respectively (Borden 1997; Lindgren and Miller 2002). Heterospecific synomones are adaptive for insects either to avoid aggregation and orientation to the wrong species or to be directed to a resource already occupied by a different species (Evenden *et al.* 1999). So, it is particularly necessary for sympatric species such as bark beetles (Pureswaran *et al.* 2004) which have overlapping pheromone molecules.

4.1.5. Push-pull strategy

Today, push-pull strategy represents an important strategy and it also called "stimulo-deterrent diversion tactic". It is a combination of deterred or repellent from the crops (push strategy) and attractive stimuli by lures (pull strategy), that control the insect pests by trapping or killing tactics. This strategy obviously requires knowledge of insect biology, chemical ecology, and the interactions between host plants and natural enemies (Miller and Cowles 1990; Khan and Pickett 2004; Cook *et al.* 2007; Khan *et al.* 2010; França *et al.* 2013). A diagrammatic graph for push-pull strategy showing how it works for controlling cereal stemborers is illustrated in Figure 1. The potential use of aphid alarm pheromone as a direct control mechanism has been explored in numerous studies. Efforts have also been made to incorporate alarm pheromones as repellents in push-pull strategies, in order to make the protected resource unattractive to the pest (Cook *et al.* 2007). Also, orientation disruption of bark beetles away from their host trees is combined with attractive semiochemical deployment in a "push-pull" tactic (Borden *et al.* 2008). Recently, Wallingford *et al.* (2017) used attract-and-kill tactic combined with oviposition deterrents as a push-pull strategy for suppressing oviposition of *Drosophila suzukii* Matsumura (Diptera: Drosophilidae). A combination of attractive mass trapping (pull), and 1-octen-3-ol, as an oviposition deterrent (push) caused high reduction in *D. suzukii* oviposition which was significantly greater than either treatment alone.

4.1.6. Other strategies using semiochemicals

Semiochemicals remain a promising and attractive research subject. Other semiochemicals

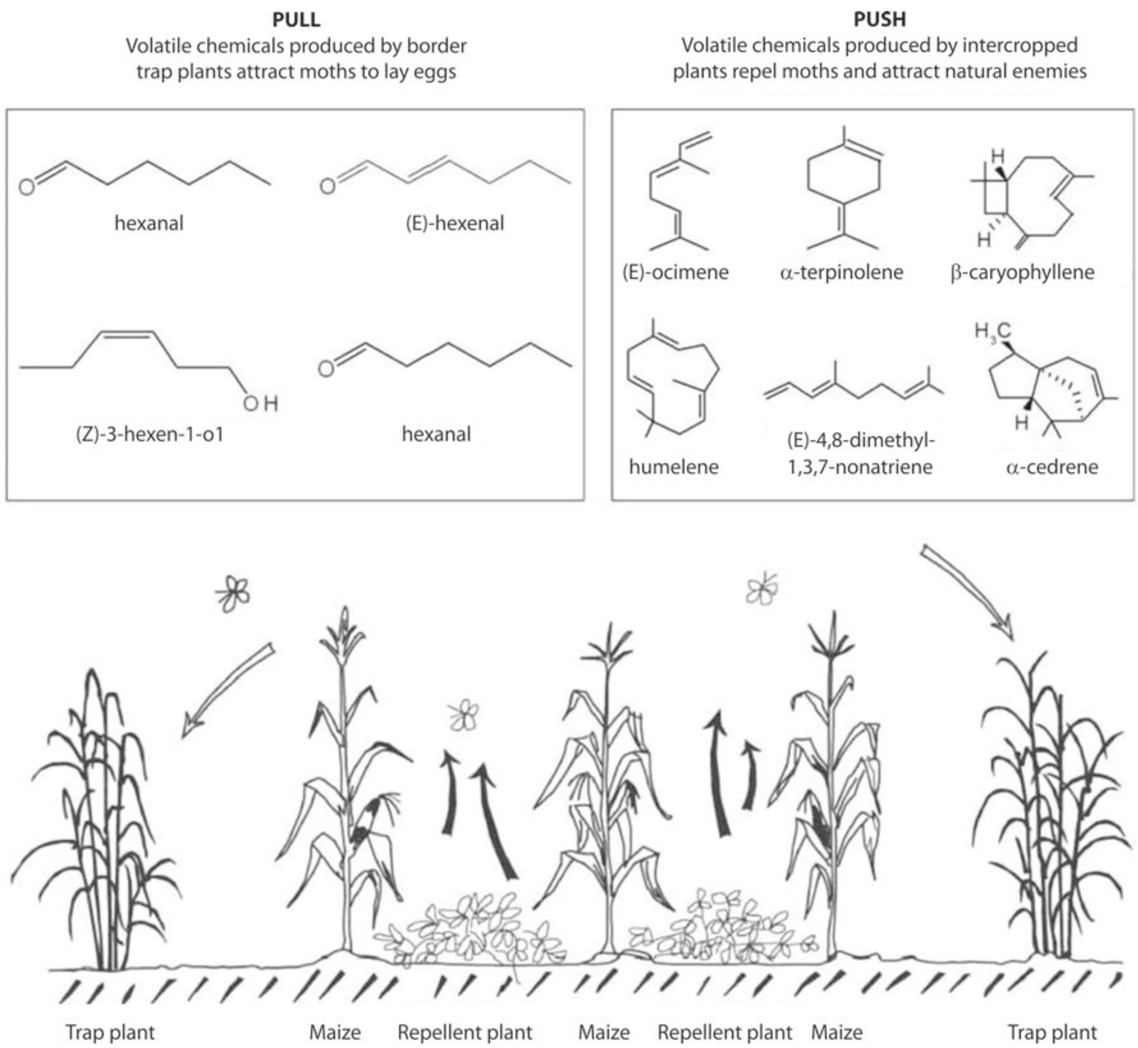

Fig. 1. Push-pull strategy for controlling cereal stems borers (Kham and Pickett 2004)

which are used to facilitate biological control of insect pests include kairomones and/or synomones. These strategies mainly depend on enhancement rearing and/or searching behavior of natural enemies in the field (Lewis and Martin 1990). These semiochemicals are used as synthetic bait or as an attractant by insects to find prey, hosts, or food. These compounds catch a wide spectrum of species that use similar resources and are frequently less attractive than pheromones (Miller and Rabaglia 2009; Zauli *et al.* 2014). Furthermore, semiochemicals are utilized to manipulate the behavioral response of beneficial natural enemies for stored product insect pests. For example, kairomones, and other interspecific chemical signals that benefit the receiver, help predators and parasitoids in direct orientation to their prey and hosts are being investigated (Brower *et al.* 1995; Phillips 1997). Also, utilization of host-plant volatiles is being studied as new active compounds for termite management (Zhu *et al*. 2003; Raina *et al*. 2003; Moawad *et al.* 2012).

Subsequently, a combination of different semiochemicals recently was used for management of some important insect pests. For example, the date palm weevil, *Rhynchophorus ferrugineus* Olivier (Coleoptera: Curculionidae) is an important insect pest causing severe damage to date palm plantations. For this reason, several tactics are adopted for managing such a weevil. Faleiro (2006) used a tactic based on coupling male aggregation pheromone (4-methyl-5-nonanol), and other semiochemical attractive substances (4-methyl-5-nonanone) which are recorded as kairomones (plant volatile origin). Such a combination has been shown to be synergistic for controlling this insect by monitoring and mass trapping tactics (Hallett *et al*. 1999).

Interestingly, active compounds extracted from insect frass can be included as new semiochemical substances that have repellent or deterrent effects against insect pests. For instance, extraction from larval frass of *Spodoptera littoralis* (Boisd.) and *Agrotis ipsilon* (Hufn.) (Lepidoptera: Noctuidae) have been evaluated for oviposition of some conspecific insects in Egypt (Ahmed *et al.* 2013). These extracts are fractionated and identified using gas chromatography-mass spectrometry. Results reveal the deterrent effect of such extracts towards oviposition of the target insects.

References

Abd El-Ghany N.M., Abdel-Wahab E.S., Ibrahim S.S. 2016. Population fluctuation and evaluation the efficacy of pheromone-based traps with different color on tomato leafminer moth, *Tuta absoluta* (Lepidoptera: Gelechiidae) in Egypt. Research Journal of Pharmaceutical, Biological and Chemical Sciences 7 (4): 1533–1539.

Abd El-Ghany N.M., Abdel-Razek A.S., Djelouah K., Moussa A. 2018. Efficacy of some eco-friendly biopesticides against *Tuta absoluta* (Meyrick). Bioscience Research 15 (1): 28–40.

Abdel-Razek A.S., Abd El-Ghany N.M., Djelouah K., Moussa A. 2017. An evaluation of some eco-friendly biopesticides against *Bemisia tabaci* on two greenhouse tomato varieties in Egypt. Journal of Plant Protection Research 57 (1): 9–17. DOI: https://doi.org/10.1515/jppr-2017-0002

Ahmed A.A.I., Hashem M.Y., Adel M.M., Mohamed S.M., Khalil S.H. 2013. Impact of *Spodoptera littoralis* (Boisd.) and *Agrotis ipsilon* (Hufn.) larval frass on oviposition of conspecific insects. Archive Phytopathology and Plant Protection 46 (5): 575–592. DOI: https://doi.org/10.1080/03235408.2012.749691

Atterholt C.A., Delwiche M.J., Rice R.E., Krochta J.M. 1999. Controlled release of insect sex pheromones from paraffin wax and emulsions. Journal of Controlled Release 57: 233–247. DOI: https://doi.org/10.1016/S0168-3659(98)00119-9

Barclay H.J., Judd G.J.R. 1995. Models for Mating Disruption by Means of Pheromone for Insect Pest Control. Researches on Population Ecology 37 (2): 239–247. DOI: https://doi.org/10.1007/BF02515826

Barrett B. 1995. Effect of synthetic pheromone permeation on captures of male codling moth (Lepidoptera: Tortricidae) in pheromone and virgin female moth-baited traps at different tree heights in small orchard blocks. Environmental Entomology 24 (5): 1201–1206. DOI: https://doi.org/10.1093/ee/24.5.1201

Beth A. 1932. Neglected Hormone. Natural Science 20: 177–183.

Borden J.H. 1997. Disruption of semiochemical mediated aggregation in bark beetles (Coleoptera: Scolytidae). p. 421–438. In: "Insect Pheromone Research: New Directions" (R.T. Cardé, A.K. Minks, eds.). Springer, Boston, MA. DOI: https://doi.org/10.100/978-1-4615-6371-6-37

Borden J.H., Lafontaine J.P., Pureswaran D.S. 2008. Synergistic blends of monoterpenes for aggregation pheromones of the mountain pine beetle (Coleoptera: Curculionidae). Journal of Economic Entomology 101 (4): 1266–1275. DOI: https://doi.org/10.1603/0022-0493(2008)101[1266:SBOMFA]2.0.CO;2

Bowers W.W., Gries G., Borden J.H., Pierce H.D.Jr. 1991. 3-Methyl-3-buten-1-ol: An aggregation pheromone of the four-eyed spruce bark beetle, *Polygraphus rufipennis* (Kirby) (Coleoptera: Scolytidae). Journal of Chemical Ecology 17 (10): 1989–2002. DOI: https://doi.org/10.1007/BF00992583

Brossut R. 1997. Phéromones: la communication chimique chez les animaux. [Pheromones: Chemical Communication in Animals]. Crusader Science, Paris, Berlin, CNRS editions, 133 pp.

Brower J.H., Smith L., Vail P.V., Flinn P.W. 1995. Biological control. p. 223–286. In: "Integrated Management of Insects in Stored Products" (B. Subramanyam, D.W. Hagstrum, eds.). Marcel Dekker, Inc. New York, 432 pp.

Burkholder W.E. 1990. Practical use of pheromones and other attractants for stored-product insects. p. 497–516. In: "Behavior-modifying Chemicals for Insect Management, Applications of Pheromones and Other Attractants" (R.L. Ridgeway, R.M. Silverstein, M.N. Inscoe, eds.). Marcel Dekker Inc., New York, 761 pp.

Butenandt A., Beckmann R., Stamm D., Hecker E. 1959. Über den Sexuallockstoff des Seidenspinners *Bombyx mori*. Reindarstellung und Konstitution. [About the sexual attractant of the silk moth *Bombyx mori* – clean presentation and constitution]. Zeitschrift fur Naturforschung 14b: 283–284.

Carter M.E., Smith M.T., Turgeon J.J., Harrison R.G. 2009. Analysis of genetic diversity in an invasive population of Asian long-horned beetles in Ontario, Canada. The Canadian Entomologist 141 (6): 582–594. DOI: https://doi.org/10.4039/n09-026

Cook S.M., Khan Z.R., Pickett J.A. 2007. The use of push-pull strategies in integrated pest management. Annual Review of Entomology 52: 375–400. DOI: https://doi.org/10.1146/annurev.ento.52. 110405.091407

Cork A. 2004. Pheromone manual. Natural Resources Institute. Chatham Maritime, ME4 4TB, UK, Chapter 4: 13–17.

Dougherty M.J., Guerin P., Ward R.D. 1995. Identification of oviposition attractants for the sandfly *Lutzomyia longipalpis* (Diptera: Psychodidae) present in volatiles of faeces from vertebrates. Physiological Entomology 20 (1): 23–32. DOI: https://doi.org/10.1111/j.1365-3032.1995.tb00797.x

Dressler R.L. 1982. Biology of the orchid bees (Euglossini). Annual Review of Ecology and Systematics 13: 373–394. DOI: https://doi.org/10.1146/annurev.es.13.110182.002105

EFSA (European Commission Food Safety Agency). 2016. A new Guidance Document on "Semiochemical active substances and plant protection products", 37 pp. Available on: https://ec.europa.eu/food/sites/food/ files/plant/docs/pesticides_ppp_app-proc_guide_doss_semiochemical.201605.pdf [Accessed: May 19, 2016]

El-Sayed A.M., Suckling D.M., Wearing C.H. 2006. Potential of mass trapping for long term pest management and eradication of invasive species. Journal of Economic Entomology 99 (5): 1550–1564. DOI: https://doi.org/10.1093/jee/99.5.1550

El-Sayed A.M., Suckling D.M., Byers J.A., Jang E.B., Wearing C.H. 2009. Potential of "Lure and Kill" in long-term pest management and eradication of invasive species. Journal of Economic Entomology 102 (3): 815–835. DOI: https://doi.org/10.1603/029.102.0301

Evenden M.L., Judd G.J.R., Borden J.H. 1999. A synomone imparting distinct sex pheromone communication channels for *Choristoneura rosaceana* (Harris) and *Pandemis limitata* (Robinson) (Lepidoptera: Tortricidae). Chemoecology 9 (2): 73–80. DOI: https://doi.org/ 10.1007/ s000490050036

Faleiro J.R. 2006. A review of the issues and management of the red palm weevil *Rhynchophorus ferrugineus* (Coleoptera: Rhynchophoridae) in coconut and date palm during the last one hundred years. International Journal of Tropical Insect Science 26: 135–150. DOI: https://doi.org/10.1079/IJT2006113

França de S.M., Mariana O.P., Cesar A.B., José V.O. 2013. The use of behavioral manipulation techniques on synthetic insecticides optimization. p. 177–196. In: "Insecticides – Development of Safer and More Effective Technologies" (S. Trdan, ed.). InTech Design team, Croatia, 548 pp. DOI: https://doi.org/10.5772/53354

Funaro C.F., Böröczky K., Vargo E.L., Schal C. 2018. Identification of a queen and king recognition pheromone in the subterranean termite *Reticulitermes flavipes*. Proceedings of the National Academy of Sciences of the United States of America 115 (15): 3888–3893. DOI: https://doi.org/10.1073/pnas.1721419115.

Hallett R., Oehlschlager A., Borden J. 1999. Pheromone trapping protocols for the Asian palm weevil, *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae). International Journal of Pest Management 45: 231–237. DOI: https://doi.org/10.1080/096708799227842

Hassan E.M., Shahat A.A., Ibrahim N.A., Vlietinck A.J., Apers S., Pieters L. 2008. A new monoterpene alkaloid and other constituents of *Plumeria acutifolia.* Planta Medica 74 (14): 1749–1750. DOI: https://doi.org/10.1055/s-0028-1088317

Hassan E.M., Matloub A.A., Aboutabl M.E., Ibrahim N.A., Mohamed S.M. 2016. Assessment of anti-inflammatory, antinociceptive, immunomodulatory, and antioxidant activities of *Cajanus cajan* L. seeds cultivated in Egypt and its phytochemical composition. Pharmaceutical Biology 54 (8): 1380–1391. DOI: https://doi.org/10.3109/13880209.2015.1078383

Hassan R.A., Hassan E.M., Ibrahim N.A., Nazif N.M. 2015. Triterpenes and cytotoxic activity of *Acokanthera oblongifolia* Hochst. growing in Egypt. Research Journal of Pharmaceutical, Biological and Chemical Sciences 6 (1): 1677–1686.

Heuskin S., Godin B., Leroy P., Capella Q., Wathelet J.P., Verheggen F., Haubruge E., Lognay G. 2009. Fast gas chromatography characterization of purified semiochemicals from essential oils of *Matricaria chamomilla* L. (Asteraceae) and Nepetacataria L. (Lamiaceae). Journal of Chromatography A. 1216 (14): 2768–2775. DOI: https://doi.org/10.1016/j.chroma.2008. 09.109

Hussain A., Phillips T.W., Mayhew T.J., AliNiazee M.T. 1994. Pheromone biology and factors affecting its production in *Tribolium castaneum.* p. 533–536. In: Proceedings of the 6th International Working Conference on Stored Product Protection (E. Highley, E.J. Wright, H.J. Banks, B.R. Champ, eds.). Canberra, Australia. Available on: http://spiru.cgahr.ksu.edu/proj/iwcspp/iwcspp6.html [Accessed: September 10, 2018]

Jones B.C., Evenden M.L. 2008. Ecological applications for pheromone trapping of *Malacosoma disstria* and *Choristoneura conflictana.* The Canadian Entomologist 140 (5): 573–581. DOI: https://doi.org/10.4039/n08-013

Karlson P., Butenandt A. 1959. Pheromones (Ectohormones) in insects. Annual Review of Entomology 4: 39–58. DOI: https://doi.org/10.1146/annurev.en.04.010159.000351

Karlson P., Lüscher M. 1959. "Pheromones" a new term for a class of biologically active substances. Nature (London) 183: 55–56. DOI: https://doi.org/10.1038/183055a0

Khan Z.R., Pickett J.A. 2004. The 'Push–Pull' strategy for stem borer management: a case study in exploiting biodiversity and chemical ecology. p. 155–164. In: "Ecological Engineering for Pest Management: Advances in Habitat Manipulations for Arthropods" (G. Gurr, S.D. Waratten, M.A. Altieri, eds.). CABI Publishing, Oxfordshire, UK.

Khan Z.R., Midega C.A.O., Bruce T.J.A., Hooper A.M., Pickett J.A. 2010. Exploiting phytochemicals for developing a 'push--pull' crop protection strategy for cereal farmers in Africa. Journal of Experimental Botany 61 (15): 4185–4196.

Knipling E.F. 1979. The Basic Principles of Insect Populations Suppression and Management. Agriculture. Agriculture Handbook No. 512, USDA, Washington DC, USA, 659 pp.

Kogan M. 1982. Plant resistance in pest management. p. 93–134. In: "Introduction to Insect Pest Management" (R.L. Metcalf, W.H. Luckmann, eds.). John Wiley and Sons, New York, 672 pp.

Larsson M.C. 2016. Pheromones and other semiochemicals for monitoring rare and endangered species. Journal of Chemical Ecology 42 (9): 853–868. DOI: https://doi.org/ 10.1007/s10886-016-0753-4

Levi-Zada A., Sadowsky A., Dobrinin S., Ticuchinski T., David M., Fefer D., Dunkelblum E., Byers J.A. 2018. Monitoring and mass-trapping methodologies using pheromones: the lesser date moth *Batrachedra amydraula.* Bulletin of Entomological Research 108 (1): 58–68. DOI: https://doi.org/10.1017/S0007485317000487

Lewis W.J., Martin W.R. 1990. Semiochemicals for use with parasitoids: status and future. Journal of Chemical Ecology 16 (11): 3067–3089. DOI: https://doi.org/10.1007/BF00979613

Lindgren B.S., Miller D.R. 2002. Effect of verbenone on five species of bark beetles (Coleoptera: Scolytidae) in lodgepole pine forests. Environmental Entomology 31 (5): 759–765. DOI: https://doi.org/10.1603/0046-225X-31.5.759

Mafra-Neto A., Fettig C.J., Unson A.S., Rodriguez-Saona C., Holdcraft R., Faleiro J.R., El-Shafie H., Reinke M., Bernardi C., Villagran K.M. 2014. Development of specialized pheromone and lure application technologies (SPLAT®) for management of Coleopteran pests in agricultural and forest systems. Chapter 15. p. 214–242. In: "Biopesticides: State of the Art and Future Opportunities" (A.D. Gross, J.R. Coats, S.O. Duke, J.N. Seiber, eds.). ACS Symposium Series Vol. 1172: American Chemical Society. Washington, DC, 291 pp. DOI: 10.1021/bk–2014–1172.ch015.

McDonough L.M., Aller W.C., Knight A.L. 1992. Performance characteristics of a commercial controlled release dispenser of sex pheromones for control of codling moth (*Cydiapo monella*) by mating disruption. Journal of Chemical Ecology 18 (12): 2177–2189. DOI: https://doi.org/10.1007/BF00984945

McPheron L.J., Seybold S.J., Storer A.J., Wood D.L., Ohtsuka T., Kubo I. 1997. Effects of enantiomeric blend of verbenone on response of *Ips paraconfusus* to naturally produced aggregation pheromone in the laboratory. Journal of Chemical Ecology 23 (12): 2825–2839. DOI: https://doi.org/10.1023/A:1022571212416

Meer R.K.V., Preston C.A. 2008. Social Insect Pheromones. p. 223–262. In: "Encyclopedia of Entomology" (J.L. Capinera, ed.). Springer, Dordrecht, 262 pp. DOI: https://doi.org/10. 1007/ 978-1-4020-6359-6_4256

Miller D.R., Rabaglia R.J. 2009. Ethanol and (-)-alpha-pinene: attractant kairomones for bark and ambrosia beetles in the southeastern US. Journal of Chemical Ecology 35 (4): 435–448. DOI: https://doi.org/10.1007/s10886-009-9613-9

Miller J.R., Strickler K.L. 1984. Plant herbivore relationships: finding and accepting host plants, p. 127–157. In: "Chemical Ecology of Insects" (W.J. Bell, R.T. Cardé eds.). Springer, Boston, MA. 523 pp. DOI: https://doi.org/10.1007/978-1-4899-3368-3_6

Miller J.R., Cowles R.S. 1990. Stimulo-deterrent diversion: a concept and its possible application to onion maggot control. Journal of Chemical Ecology 16 (11): 3197–3212. DOI: https://doi.org/10.1007/BF00979619

Moawad S.S., Al.-Barty A., Al-Otaibi N.J. 2012. Behavioural response of *Antacanthotermes ochraceus* towards some bates and volatile oils. Journal of Agricultural Science and Technology B2: 1279–1286. DOI: https://doi.org/10.17265/2161-6264/2012.12B.009

Morrison W.R., Lee D.H., Reissig W.H., Combs D., Leahy K., Tuttle A., Cooley D., Leskey T.C. 2016. Inclusion of specialist and generalist stimuli in attract-and-kill programs: Their relative efficacy in apple maggot fly (Diptera: Tephritidae) pest management. Environmental Entomology 45 (4): 974–982. DOI: https://doi.org/10.1093/ee/nvw043

Nishida R. 2002. Sequestration of defensive substances from plants by Lepidoptera. Annual Review of Entomology 47: 57–92. DOI: https://doi.org/10.1146/annurev.ent.47.091201. 145121

Nordlund D.A., Lewis W.J. 1976. Terminology of chemical releasing stimuli in intraspecific and interspecific interactions. Journal of Chemical Ecology 2 (2): 211–220. DOI: https://doi.org/ 10.1007/BF00987744

Phillips T.W. 1994. Pheromones of stored-product insects: current status and future perspectives. p. 479–486. In: Proceedings of the 6th International Working Conference on Stored Product Protection (E. Highley, E.J. Wright, H.J. Banks, B.R. Champ). Canberra, Australia, 1274 pp.

Phillips T.W. 1997. Semiochemicals of stored-product insects: research and applications. Journal of Stored Product Research 33 (1): 17–30. DOI: https://doi.org/10.1016/S0022-474X(96)00039-2

Piñero J.C., Dudenhoeffer A.P. 2018. Mass trapping designs for organic control of the Japanese beetle, *Popillia japonica* (Coleoptera: Scarabaeidae). Pest Management Science 74 (7): 1687–1693. DOI: https://doi.org/10.1002/ps.4862

Poland T.M., Borden J.H. 1997. Attraction of a bark beetle predator, *Thanasimus undatulus* (Coleoptera: Cleridae), to pheromones of the spruce beetle and two secondary bark beetles (Coleoptera: Scolytidae). Journal of the Entomological Society of British Columbia 94: 35–41.

Prokopy R.J., Averill A.L., Bardinelli C.M., Bowdan E.S., Cooley S.S., Crnjar R.M., Dundulis E.A., Roitberg C.A., Spatcher P.J., Tumlinson J.H., Weeks B.L. 1982. Site of production of an oviposition-deterring pheromone component in *Rhagoletis pomonella* flies. Journal of Insect Physiology 28 (1): 1–10. DOI: https://doi.org/10.1016/0022-1910(82)90016-6

Prokopy R.J., Roitberg B.D., Averill A.L. 1984. Chemical mediation of resource partitioning in insects. p. 301–330. In: "The Chemical Ecology of Insects" (W.J. Bell, R.T. Cardé, eds.). Chapman and Hall, London, 523 pp.

Prokopy R.J., Wright S.E., Black J.L., Hu X.P., McGuire M.R. 2000. Attracticidal spheres for controlling apple maggot flies commercial-orchard trials. Entomologia Experimentalis et Applicata 97 (3): 293–299. DOI: https://doi.org/10.1046/j.1570-7458.2000.00742.x

Pureswaran D.S., Gries R., Borden J.H. 2004. Antennal responses of four species of tree-killing bark beetles (Coleoptera: Scolytidae) to volatiles collected from beetles, and their host and nonhost conifers. Chemoecology 14 (2): 59–66. DOI: https://doi.org/10.1007/s00049-003-0261-1

Raina K.A., Bland J.M., Dickens J.C., Park Y.I., Hollister B.J. 2003. Premating behavior of dealates of the Formosan subterranean termite and evidence for the presence of a contact sex pheromone. Journal of Insect Behavior 16 (2): 233–245. DOI: https://doi.org/10.1023/ A:1023967818906

Reddy G.V.P., Guerrero A. 2004. Interactions of insect pheromones and plant semiochemicals. Trends in Plant Science 9 (5): 253–261. DOI: https://doi.org/10.1016/j.tplants.2004.03.009

Rhainds M., Kettela E.G., Silk P.J. 2012. Thirty five years of pheromone-based mating disruption studies with *Choristoneura fumiferana* (Clemens) (Lepidoptera: Tortricidae). The Canadian Entomologist 144 (3): 379–395. DOI: https://doi.org/10.4039/tce.2012.18

Rhainds M., Therrien P., Morneau L. 2016. Pheromone-based monitoring of spruce budworm (Lepidoptera: Tortricidae) larvae in relation to trap position. Journal of Economic Entomology 109 (2): 717–723. DOI: https://doi.org/10.1093/jee/tov393

Salib J.Y., El-Toumy S.A., Hassan E.M., Shafik N.H., Abdel-Latif S.M., Brouard I. 2014. New quinoline alkaloid from *Ruta graveolens* aerial parts and evaluation of the antifertility activity. Natural Product Research 28 (17): 1335–1342. DOI: https://doi.org/10.1080/ 14786419.2014.903395

Singer M.C. 1986. The definition and measurement of oviposition preference in plant-feeding insects. p. 65–94. In: "Insect-Plant Interactions" (J.R. Miller, T.A. Miller, eds.). Springer Series in Experimental Entomology. Springer, New York, NY, 342 pp. DOI: https://doi.org/10.1007/978–1–4612–4910–8_3.

Stelinski L.L. 2007. On the physiological and behavioral mechanisms of pheromone-based mating disruption. Pestycydy 3 (4): 27–32.

Stelinski L.L., Liburd O.E. 2001. Evaluation of various deployment strategies of imidacloprid-treated spheres in highbush blueberries for control of *Rhagoletis mendax* (Diptera: Tephritidae). Journal of Economic Entomology 94 (4): 905–910. DOI: https://doi.org/10.1603/0022-0493-94.4.905

Stelinski L.L., Oakleaf R., Rodriguez-Saona C. 2007. Oviposition-deterring pheromone deposited on blueberry fruit by the parasitic wasp, *Diachasma alloeum*. Behaviour 144 (4): 429–445. DOI: https://doi.org/10.1163/156853907780755996

Turlings T.C.J., Tumlinson J.H., Lewis W.J. 1990. Exploitation of herbivore-induced plant odors by host-seeking parasitic wasps. Science 250 (4985): 1251–1253. DOI: 10.1126/science. 250.4985.1251

Vandermoten S., Mescher M.C., Francis F., Haubruge E., Verheggen F.J. 2012. Aphid alarm pheromone: An overview of current knowledge on biosynthesis and functions. Insect Biochemistry and Molecular Biology 42 (3): 155–163. DOI: https://doi.org/10.1016/ j.ibmb.2011.11.008

Vilela E.F., Della Lucia M.T. 2001. Feromônios de insetos: biologia, química e emprego no manejo de pragas. [Insect Pheromones: Biology, Chemistry and Employment in Pest Management]. 2nd ed. Holos Publishing House, Ribeirão Preto, Brazil, 206 pp. (in Portuguese)

Wallingford A.K., Cha D.H., Loeb G.M. 2017. Evaluating a push-pull strategy for management of *Drosophila suzukii* Matsumura in red raspberry. Pest Management Science 74 (1): 120–125. DOI: https://doi.org/10.1002/ps.4666

Weatherston I., Minks A.K.1995. Regulation of semiochemicals – global aspects. Integrated Pest Management Reviews 1 (1): 1–13. DOI: https://doi.org/10.1007/BF00140330

Weinzierl R., Henn T., Koehler P.G., Tucker C.L. 2005. Insect attractants and traps. University of Florida IFAS Extension. 9 pp. Available on: http://ufdc.ufl.edu/ IR00002794/00001 [Accessed: September 10, 2018]

Wilson E.O. 1971. The Insect Societies. The Belknap Press of Harvard University Press, Cambridge, MA, USA, 562 pp.

Witzgall P., Kirsch P., Cork A. 2010. Sex pheromones and their impact on pest management. Journal of Chemical Ecology 36 (1): 80–100. DOI: https://doi.org/10.1007/s10886-009-9737-y

Zauli A., Chiari S., Hedenstrom E., Svensson G.P., Carpaneto G.M. 2014. Using odour traps for population monitoring and dispersal analysis of the threatened saproxylic beetles *Osmoderma eremita* and *Elater ferrugineus* in central Italy. Journal of Insect Conservation 18 (5): 801–813. DOI: https://doi.org/10.1007/s10841-014-9687-8

Zhu B.C.R., Henderson G., Sauer A.M., Yu Y., Crowe W., Laine R.A. 2003. Structure-activity of valencenoid derivatives and their repellency on the Formosan subterranean termite. Journal of Chemical Ecology 29 (12): 2695–2701. DOI: https://doi.org/10.1023/ B:JOEC.0000008013.07845.4c