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Editorial

Novel trends on semiochemicals and semiophysicals for insect science and management

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Multimodal plant protection tactics based on olfactory, gustatory, visual or acoustic signals are various and have a high potential to improve existing integrated pest management (IPM) strategies (Gross & Gündermann 2016). Infosignals consisting of semiochemicals (syn. infochemicals) and semiophysicals (Hill et al. 2019) convey information on interactions between individuals, releasing a behavioural or physiological response in the receiver (Čokl & Millar 2009; Nieri et al. 2022). Dicke & Sabelis (1988) divided semiochemicals in pheromones, which mediate interactions between organisms of the same species, and allelochemicals, which mediate interactions between heterospecifics. Semiochemicals are part of insect odorscapes and include volatile organic compounds (VOCs) that are used by insects as chemical cues to locate different resources, such as food (allelochemicals, e.g., kairomones), mate (sex pheromones), or enemies (allelochemicals, e.g., kairomones) (Conchou et al. 2019). The manipulation of odorscapes of insect pests is a promising and more sustainable crop protection tactic in alternative to pesticides (Franco, 2020). In comparison to conventional insecticides, semiochemicals offer much lower toxicity and reduced side effects on non-target species and environment (Thöming 2021). Pheromones have been applied in sustainable plant protection strategies, as they are high species-specific, non-toxic and active in very small amounts. Sex pheromones can be used both for monitoring pest insects and for disturbing their mating behaviour (mating disruption technique), while aggregation pheromones have a potential in mass trapping (Gross 2013; Harari 2016). Recently, it was shown that climate change negatively affects pheromone application in pest management (El Sayed et al. 2021). Thus, there is a need for improving the stability of semiochemicals under increasing temperatures and UV radiation through the development of more efficient chemical stabilisers including heat tolerant formulations by microencapsulation or nano-fibre formulation or other smart formulations that can protect semiochemicals from degradation (El Sayed et al. 2021). Behavioural studies on odour-mediated host plant – insect relationships should be also further developed in future research, particularly if the goal is to use allelochemicals in pest control (Thöming 2021).

Many novel trends, chemical and physical formulations and research directions are reported in the present Special Issue, which subsumed contributions from leading experts in the growing research field on semiochemicals and semiophysicals, mainly in an applied context. Five reviews and four original research articles have been included after rigorous peer-review, focusing on all aspects of infosignals in insect science and management.

The review by Nieri et al. (2022) introduces the term semiophysicals as opposed to semiochemicals and focuses on pest behavioural manipulation. They discuss the manipulation of pest orientation through attractive/repellent stimuli, the inhibition or promotion of specific pest behaviours, and interferences with intraspecific communication through disruptive stimuli. For each approach, the authors provide examples for the use of both semiochemicals and semiophysicals.

The comprehensive review by Gross et al. (2022) aims at providing an overview of interactions between phloem-restricted bacterial plant pathogens and their vector insects, which are mediated by primary and secondary plant metabolites. It is organized in a bibliographic oriented part describing the current knowledge of phloem and volatile metabolite mediated interactions between pathogens, their host plants, their vector insects, and where information is available, their antagonists. This part is followed by a comprehensive synthesis of the reviewed literature, including novel trends on pest management strategies of phloem-restricted bacteria, in which semiochemicals are applied. Important research gaps were identified and an outlook on future prospects is given.

Herbivorous mites commonly co-occur with several species of phytoseiid predatory mites, which may engage in intraguild predation. Predator mite decision-making relies on their ability to recognize odours signalling the presence

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of the herbivore but also that of potential competitors/predators. The case study by Cruz-Miralles et al. (2022) revealed that the volatile signature of each predatory mite is species specific, the predators' foraging behaviour is affected by heterospecific predator odours, and predator responses strongly depend on the host plant.

Due to the high volatility and chemical instability against UV light and oxidation, the use of semiochemicals in plant protection often remains limited. Appropriate formulations can protect them from environmental factors and may improve release performance and duration triggering a desired reaction in the target organism at the place of application. The review by Muskat & Patel (2022) provides an overview of recent innovations in semiochemical formulation developed for insect behaviour manipulation, with an emphasis on formulation aspects and formulation potential for slow and controlled release of semiochemicals. The focus in their review was set on inventions and studies aiming to elucidate material and formulation properties that affect targeted semiochemical release.

Another emphasis of this special issue is on mating disruption (MD) of pest insects. We start with a review on the scientific and technological developments in mating disruption of scale insects by Franco et al. (2022). Only recently, MD has been integrated in pest management of insect taxa other than Lepidoptera, such as scale insects. The authors present an overview of different aspects related with the identification and analysis of scale sex pheromones, the biological traits that may influence the effectiveness of MD, and the involved mechanisms. They then summarise what is known about the development and application of MD formulations in pest management of scales, and provide data on the actual worldwide use of MD against scales. Finally, they discuss the future prospects on the topic. The risk of resistance to MD in moths is reviewed by Harari & Sharon (2022). The review outlines the pathways that may lead to reduced sensitivity or resistance to MD, suggesting three main factors that may elicit resistance, namely a change in the pheromone composition emitted by calling females, the use of synthetic molecules that represent only a partial blend out of the sex pheromone bouquet, and restricted gene flow within the population. Multispecies formulations may contribute to reducing application costs of MD. Ricciardi et al. (2022) provide an example of this approach by presenting the results of two-year field experiments to evaluate the effectiveness a new double dispenser for simultaneous MD of the European grapevine moth and the vine mealybug. A new approach for pest management of the codling moth in apple, by combining female removal with MD was tested by Knight et al. (2022). The authors evaluated different lures and examined the importance of trap type and density on moth catches. The results showed the levels of fruit injury could be reduced 50-75% across each moth flight.

Finally, Golov et al. (2022) investigated the possible influence of female "quality" on male behaviour, using the nocturnal pink bollworm moth as a model. They provide experimental evidence that the pheromone-mediated mating system in moths incorporates information used for mate-finding and mate-assessment, with a possible source-detection mechanism, by which female quality may influence the likelihood of a successful mate-finding.

Overall, we are convinced that this Special Issue extensively reflects novel trends on semiochemicals and semiophysicals for insect pest management, and we hopefully expect that it may inspire other scientists to intensify research on the challenges outlined in the published original articles and reviews.

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