(wileyonlinelibrary.com) DOI 10.1002/ps.8883

Harnessing chemical ecology for improved pest management- advances and future opportunities

Abstract

One aspect of chemical ecology is the study of interactions between organisms across trophic levels that are mediated by naturally occurring chemicals. These chemical cues are produced by organisms, including plants, insects, and microorganisms, enabling them to communicate intra- and inter-specifically. These cues can be exploited for the management of pests that affect crops through several mechanisms, including, but not limited to, inducing plant defences against pests, direct suppression of pests, and signalling to beneficial predators/parasitoids for pest control. Identifying the chemical cues (semiochemicals) involved in these biological activities, and advancing our understanding of their roles could enable the development of novel, sustainable tools to increase crop productivity. This special issue presents 21 articles published in Pest Manag. Sci. from 2023 to 2025 that report on plant-insect-microbe interactions and microbe-insect interactions. This editorial has a brief overview of manuscripts from the special issue, highlighting substantial advancements in chemical ecology research and priorities for future research. We hope this special issue inspires new ideas for the future of chemical ecology research, highlights opportunities for joint and collaborative approaches, and showcases cutting-edge research that can advance the field forward in tackling global pest management challenges in agricultural and horticultural crops.

Keywords: chemical ecology; semiochemicals; integrated pest management; volatile organic compounds; *Arma custos*; *Riptortus pedestris*; *Ceratitis capitata*; *Sitobion avenae*; *Delia platura*; *Stegasta bosqueella*; *Bemisia tabaci*; *Phthorimaea operculella*; *Sogatella furcifera*; *Spodoptera frugiperda*; *Tetranychus urticae*; *Psylliodes chrysocephala*; *Ips typographus*; *Xylosandrus germanus*; *Xylosandrus crassiusculus*; *Anisandrus maiche*

1 INTRODUCTION

Substantial increases in agricultural productivity are required to provide sufficient food for a growing global population. Crop pests (encompassing insects, pathogens, and weeds) cause major constraints to crop production, reducing food crop yields and quality.[1] To address these losses, the application of chemical inputs, including broad-spectrum chemical pesticides, has been adopted to manage these pests, which has been instrumental in reducing losses. However, over-use of these inputs can result in pesticide resistance, rendering them less effective, and can pose several negative impacts on the environment and human health. It is therefore necessary to develop alternative, more environmentally sustainable pest management strategies.

Chemical ecology is the study of chemically-mediated interactions between organisms, through the production of chemical cues and toxins.[2] Some of these naturally-occurring, behaviour- and development-modifying chemicals (semiochemicals) act through non-toxic modes of action, and are produced by plants, insects, and microorganisms.[3–5] These chemical cues can be exploited for pest management through several mechanisms, including, but not limited to, induced plant defences against pests, direct suppression of pests, and signalling to beneficial predators/parasitoids for pest control.[6] The chemical cues could therefore be applied as attractants, repellents, oviposition deterrents, traps, and fumigants for pest management, offering more sustainable methods for pest control compared to current methods. Identifying the chemical cues involved in these biological activities, and advancing our understanding of their biological roles, will enable the development of novel, sustainable tools to increase crop productivity.

This special issue, entitled 'Harnessing chemical ecology for improved pest management' comprises papers contributed by internationally recognised researchers, who investigate different aspects of pest management. Together, these papers highlight substantial progress in the field of chemical ecology, enhancing our understanding of how chemical interactions between plants, insects, and microorganisms can be harnessed for sustainable pest management. To conclude, we offer several key priority areas for future research.

2 CHEMICAL ECOLOGY AND PEST MANAGEMENT

Significant advances in chemical ecology research are described in this special issue of *Pest Management Science*. Xu *et al.*[7] provide fundamental insights into how insect rearing can impact pheromone production from stink bugs (*Arma custos* and *Riptortus pedestris*), which could have broader implications in conducting pest management research. They demonstrate that the rearing conditions of stink bugs can impact their volatile chemical composition, relating to their gland composition. This highlights an important area for consideration, which could be translated in other insect species, and could lead to the optimised design of biocontrol strategies when rearing insect species.

The Mediterranean fruit fly (*Ceratitis capitata*) is an important pest of fruits and vegetables in tropical and subtropical areas,

for which semiochemical-based strategies are required for monitoring and management. Tabanca *et al.*[8] have identified new attractive kairomones for the Mediterranean fruit fly, based on thymol and carvacrol ethers, with improved longevity of attraction compared to the tea tree oil (*Melaleuca alternifolia*) positive control. These findings could aid the development of more attractive, persistent ethers which are more effective than their parent compounds, potentially leading to improved semiochemical-based management strategies for this pest.

Aphids are a major crop pest of global importance, causing substantial losses due to direct feeding, and the transmission of viruses on both arable and horticultural crops. Two contributions by Borg *et al.*[9] provide substantial advances in our understanding of aphid pest management. First of all, the volatile organic compound (VOC)-mediated aphid behaviours involved in antixenosis were investigated by examining the response of the grain aphid *Sitobion avenae* to ancestor wheat (*Triticum monococcum*). They use behavioural and electrophysiological experiments to demonstrate the role for VOCs in aphid antixenosis by *T. monococcum*. Secondly, they provide a comprehensive overview of metabolite-based resistance in wheat varieties to virus vectors, including current knowledge gaps and future research directions.[10]

The application of plant hormones as seed treatments is another potential method of sustainable pest management, through eliciting host plant defences against insect pests. Ray *et al.*[11] applied methyl jasmonate to corn seeds (*Zea mays*), which led to reductions in the oviposition of the corn seed maggot *Delia platura* compared to control treatments, as well as reducing larval performance, in both laboratory and field tests. These findings highlight the potential use for methyl jasmonate as a seed treatment for the management of insect pests, and demonstrate the efficacy of the treatments under open field conditions.

Whilst most studies investigating plant-insect interactions focus on aboveground insect pests, there is a need to increase the understanding of plant-pest chemical interactions belowground, due to the cryptic nature of belowground pests. Li *et al.*[12] examined the role of the root-secreted signaling molecule (−)-loliolide in triggering chemical defences in rice and wheat against weeds, pathogens and herbivores, through altering the expression of a range of defence-related genes.[12] The compound also induced rice resistance against the fungal pathogen *Rhizoctonia solani*, through mediating defence hormone biosynthesis. The molecule could have potential applications in pest management and could be integrated into cropping systems in agricultural settings.

The rednecked peanutworm (*Stegasta bosqueella*) causes major constraints to peanut crop production, and the application of chemical insecticides have been insufficient in managing their populations. Pinto *et al.*[13] have developed an attract-and-kill method targeting the pest. This method reduces damage to peanut crops under field conditions, based on the semiochemical linalyl alcohol. Significantly reduced populations of the larvae were achieved over two growing seasons, highlighting the method as a potential tool for the management of *S. bosqueella* larvae and adult moths.

Bemisia tabaci (whitefly) is an herbivorous insect pest of global concern, which can lead to substantial losses in a range of economically important crops. Two manuscripts submitted to the special issue drive forward research efforts in the sustainable management of the pest. Firstly, Zhang *et al.*[14] demonstrated that VOC s produced by *Nicotiana benthamiana* are more attractive to whitefly compared to *Nicotiana tabacum* VOCs, suggesting differences in VOC production between the two *Nicotiana* species. Analytical and behavioural experiments highlighted undecane as an attractant compound, which, when placed into sticky traps, increased the number of trapped insects compared to control traps. This demonstrates the optimisation of sticky traps with undecane could lead to improved management of whiteflies, potentially reducing the overreliance on insecticides which are the current primary management strategy against this pest. Secondly, Wu *et al.*[15] investigate the importance of two phytohormones (jasmonic acid (JA) and salicy lic acid (SA)) in whitefly resistance. They identify inducible promoters involved in SA and JA regulation in *N. tabacum* and further demonstrate that SA-inducible promoters lead to increases in the expression of JA-regulated genes following whitefly infestation. Together, these manuscripts highlight progress in the design of integrated pest management strategies for the control of whitefly.

The potato tuber moth *Phthorimaea operculella* is an arthropod pest of potato, placing substantial constraints on production. Pheromones are a commonly used tool for the monitoring and management of pests, and the pheromone bouquet of *P. operculella* comprises two compounds (4*E*,7*Z*-trisadene-1-ol acetate and 4*E*,7*Z*,10*Z*-trisadene-1-ol acetate). Yan *et al.*[16] aimed to use synthetic analogues of these pheromones as potential alternative management tools, due to their increased stability in the field and the ability to synthesize them at larger scales. They designed and synthesised 11 sex pheromone analogues and found three which exhibited significant trapping effects under field conditions, highlighting progress in using analogues of insect sex pheromones for more cost-effective pest management.

The white-backed planthopper (WBPH) *Sogatella furcifera* is a serious pest of rice, reducing yields through phloem feeding, as well as acting as a vector for bacterial and viral diseases. He *et al.*[17] identified several genes from within the takeout gene family, which are involved in olfactory-associated roles impacting physiological and behavioural functions in insects. They revealed that a specific gene (*SfTO17*) is enriched in planthopper antennae, with a high affinity for the plant derived semiochemical β-ionone. When the gene was knocked down using RNAi, the WBPH olfaction was disrupted, and host-seeking responses were reduced. This demonstrates a role for the protein in the olfaction of WBPH and provides a novel target for controlling the pest.

The fall armyworm *Spodoptera frugiperda* is a polyphagous pest of global importance which causes substantial crop losses to a broad range of arable crops, including maize, sorghum, sugarcane and soybean. The global importance of this pest is demonstrated by the submission of several manuscripts in this special issue, which all aim to develop novel, sustainable management strategies against this pest. Gandham *et al.*[18] investigated VOC production at different phenological stages of soybean (*Glycine max*), and the influence of plant developmental stage on the oviposition of *S. frugiperda*. Gravid *S. frugiperda* preferred the vegetative stage of growth, which exhibited significantly higher VOC emissions and trichome densities, relative to the reproductive stage of development of the plant. These findings highlight an important research consideration in plant development and pest behaviours, and could highlight the use of relay cropping in sustainable management practices. A second manuscript on fall armyworm management, from Xu *et al.*,[19] examines the use of plant-based insecticides to manage *S. frugiperda*. Two essential oils from *Periplocae cortex*, a medicinal plant, were tested for a role in the olfactory behaviour and oviposition of *S. frugiperda*. The compounds, *p*-methyl benzaldehyde and 2-hydroxy-5-methoxybenzaldehyde, showed

significant avoidance effect on the olfactory behaviour and oviposition of the pest, and inhibited its fertility. This demonstrates the potential for plant essential oils in the sustainable management of fall armyworm. A third manuscript addressing fall armyworm management, from Pereira *et al*.,[20] investigates the use of silicon (Si) fertilization to manage *S. frugiperda*, and the role of Si on VOC production. Si was shown to enhance the attractiveness of herbivore-induced plant VOCs from maize to the predatory earwig *Doru luteipes* when the plants are infested with the fall armyworm, *S. frugiperda*. The authors found that Si-fertilized plants emitted a terpene, neryl acetate, which was specifically attractive to the earwig, suggesting that Si can act as a priming agent for indirect plant defences, thereby contributing to suppressing insect pest populations.

Lima bean (*Phaseolus lunatus*) is a leguminous crop of global importance, providing an important source of protein to consumers. The spider mite, *Tetranychus urticae*, is a pest of lima bean, which can substantially reduce yields through piercing and sucking the foliar tissue of plants, reducing their quality and yields. Li *et al*.[21] demonstrated that herbivory of *T. urticae* on lima bean leaves, as well as treatment with alamethicin, induced the production of flavonoid biosynthesis pathways in the crop. Performance assays using quercetin, a downstream product of the flavonoid biosynthesis pathway, showed that quercetin treatments significantly reduced survival rates and number of eggs laid on plants. This study highlights the mechanisms underpinning lima bean interactions with the spider mite and identifies genes that could be of interest for engineering crop resistance to the pest.

Another crop of global importance, oilseed rape (OSR) (*Brassica napus*), is under increasing pressure due to the cabbage stem flea beetle *Psylliodes chrysocephala* (CSFB) and was the topic of a previous special issue in Pest Management Science.[22] One study aimed to determine the behavioural responses of CSFB to OSR, using olfactometer tests.[23] They demonstrated that female CSFB were attracted to VOCs from mechanically damaged OSR plants, whereas undamaged plants were not attractive towards the beetle; however, damaged seedlings of different species were not attractive. This response also appeared to be sex-specific, with only females displaying attraction. Field assays with one attractive compound, allyl isothiocyanate, showed significantly increased attraction compared to controls. This study demonstrates the potential use for field application of attractive compounds, providing an important step forward for the sustainable management of CSFB.

Whilst the majority of manuscripts featured in this special issue focus on arable crop pests, novel insights into the behaviour and development of a devastating forest pest in Europe have also been reported. The eight-toothed spruce bark beetle *Ips typographus* (Coleoptera: Scolytinae) has caused substantial damage to Norway spruce (*Picea abies*) forests in Europe in recent years. For the first time, *I. typographus* has established localised breeding populations in Britain. Sitka spruce (*Picea stichensis*) is the principal conifer species grown in UK plantation forestry, and while the interactions between *I. typographus* and Norway spruce are well understood, there is limited knowledge about Sitka spruce's susceptibility to the beetle. Inward *et al*[24] show that *I. typographus* can preferentially choose Sitka spruce over Norway spruce for breeding and uses VOC s to locate its primary host. The study provides important data on the potential risks of *I. typographus* establishment in Sitka Spruce growing regions of the UK.

Oviposition is an important activity for female insects, influencing their fitness and the survival of their offspring, and the location of suitable insect oviposition is guided by the detection of olfactory cues. The research reviewed by Zhan and Wang[25] highlight the sources, chemical composition, and biological significance of oviposition-deterring pheromones (ODPs) in insects, highlighting their role in influencing oviposition behavior and ecological balance. ODPs are crucial for inter- and intraspecific communication and have potential applications in pest management strategies.

Invasive ambrosia beetles (Coleoptera: Curculionidae: Scolytinae), specifically *Xylosandrus germanus* (Blandford), *X. crassiusculus* (Motschulsky), and *Anisandrus maiche* (Kurentzov) are destructive wood-boring pests of apple trees (*Malus domestica*) in the eastern United States. Tobin *et al*.[26] evaluated research on a push-pull strategy using verbenone to manage ambrosia beetle populations in eastern apple orchards. The findings indicated that verbenone effectively reduces beetle captures without the need for a pull factor, particularly when deployed near woodlot edges. This study provides new avenues of research to develop sustainable management programs for apple orchards.

3 CONCLUSIONS AND FUTURE DIRECTIONS

This special issue focuses on how chemical ecology can be manipulated to enhance the development of sustainable management practices for current and future agriculture, and deliver scientific solutions to national and global agricultural challenges. Harnessing these chemical cues derived from plants, insects, and microorganisms could provide a key avenue to enhance pest management practices. The manuscripts published in this special issue highlight innovative research across the chemical ecology research community, taking substantial steps forward in sustainable pest management. Moving forward, we highlight potential future priorities:

- Field testing of bioactive compounds, for both pest monitoring and management, which can bridge the gap between laboratory findings and practical applications.
- Continued dialogue between academia, growers, nurseries, and industry to help address current agricultural challenges and develop industrial-scale applications for pest management solutions based on chemical cues[27].
- The use of next-generation sequencing methods and image-based model technologies for early pest detection.
- Increasing the awareness and support from policymakers, for the adoption of IPM (Integrated Pest Management) in agricultural systems.
- Continued national and international collaboration, through sharing knowledge and expertise, capacity building and training, and global responses to emerging pests are critical steps in the implementation of novel pest management strategies.
- Determining the effect of environmental change on chemical communication between microorganisms.
- Validation of pheromones/semiochemicals in combination with other IPM methods (e.g. pest-resistant crops, use with other biologicals for biocontrol).
- Improved detection methods enabling in-field diagnostic of pests and diseases, which could exploit the production of VOC s from plants.

ACKNOWLEDGEMENTS

Rothamsted Research receives strategic funding from the Biotechnology and Biological Sciences Research Council (BBSRC) of the United Kingdom, including from the Growing Health Institute strategic program [BB/X010953/1; BBS/E/RH/230003A] and Smart Crop Protection strategic program (BBS/OS/CP/000001). This research was partly supported by the United States Department of Agriculture, Agricultural Research Service (USDA-ARS) (Project Number: 6038-22000-007-00D). The authors are grateful for the comments of Dr. Mike Birkett (Rothamsted Research, UK) and Dr. Alden Estep (USDA-ARS, CMAVE Gainesville, FL, USA) for providing reviews on an earlier version of the manuscript. We also acknowledge Dr. John Beck (USDA-ARS, CMAVE Gainesville, FL, USA) as the editor of this special issue for his excellent compilation work and criticism, which made this special issue a gratifying project. We wish to express our appreciation to all authors and reviewers for their contributions, and the Pest Management Science staff for their guidance and effort in the editorial process. Finally, we want to thank Dr. Stephen Duke (University of Mississippi, Oxford, MS, USA) for his support of the concept of this Special Issue.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

Gareth Thomas
Protecting Crops and the Environment, Rothamsted Research, Harpenden, UK
gareth.andrew.thomas.12@gmail.com
Nurhayat Tabanca
USDA-ARS, Subtropical Horticulture Research Station, Miami, Florida, USA

REFERENCES

1 Savary S, Willocquet L, Pethybridge SJ, Esker P, McRoberts N and Nelson A, The global burden of pathogens and pests on major food crops. *Nat Ecol Evol* **3**:430–439 (2019).
2 Beck JJ, Alborn HT, Block AK, Christensen SA, Hunter CT, Rering CC *et al*., Interactions among plants, insects, and microbes: elucidation of inter-organismal chemical communications in agricultural ecology. *J Agric Food Chem* **66**:6663–6674 (2018).
3 Davis TS, Crippen TL, Hofstetter RW and Tomberlin JK, Microbial volatile emissions as insect semiochemicals. *J Chem Ecol* **39**:840–859 (2013).
4 Weisskopf L, Schulz S and Garbeva P, Microbial volatile organic compounds in intra-kingdom and inter-kingdom interactions. *Nat Rev Microbiol* **19**:391–404 (2021).
5 Ninkovic V, Markovic D and Rensing M, Plant volatiles as cues and signals in plant communication. *Plant Cell Environ* **44**:1030–1043 (2021).
6 Thomas G, Rusman Q, Morrison WR, Magalhães DM, Dowell JA, Ngumbi E *et al*., Deciphering plant-insect-microorganism signals for sustainable crop production. *Biomolecules* **13** (2023).
7 Xu H, Hu T, Li X, Song L, Yang S, Meng L *et al*., Adaptive changes in pheromone production and release under rearing conditions in stink bugs. *Pest Manag Sci* (2023).
8 Tabanca N, Cloonan KR, Nesterkina M, Gill MA, Montgomery WS, Kravchenko I *et al*., Behavioral and electrophysiological responses of the male medfly, *Ceratitis capitata*, to thymol and carvacrol ethers. *Pest Manag Sci* (2024).
9 Borg AN, Vuts J, Caulfield JC, Withall DM, Foulkes MJ and Birkett MA, Characterisation of aphid antixenosis in aphid-resistant ancestor wheat, *Triticum monococcum*. *Pest Manag Sci* (2024).
10 Borg AN, Vuts J, Caulfield JC and Birkett MA, Metabolite-based resistance in wheat varieties to aphid virus vectors: progress and future opportunities. *Pest Manag Sci* (2025).
11 Ray S, Hsu G, Pappous NT, Rooney O, Taylor AG and Thaler JS, Effects of methyl jasmonate seed treatments on adult oviposition preference and larval performance of seed corn maggot (*Delia platura*) in corn (*Zea may*). *Pest Manag Sci* (2024).
12 Li Z, Jia F, Li L and Kong C, Root-secreted (−)-loliolide mediates chemical defense in rice and wheat against pests. *Pest Manag Sci* (2024).
13 Pinto JRL and Fernandes OA, Successful management of *Stegasta bosqueella* (Lepidoptera Gelechiidae) in peanut with an attract-and-kill strategy. *Pest Manag Sci* (2024).
14 Zhang X, Han W, Zhang F, Wang J, Liu S and Wang X, Attraction of *Nicotiana benthamiana* to *Bemisia tabaci* is related to a chemical signal in plant volatile, undecane. *Pest Manag Sci* (2024).
15 Wu H, Han W, Liang K, Wang J, Zhang F, Ji S *et al*., Using salicylic acid-responsive promoters to drive the expression of jasmonic acid-regulated genes enhances plant resistance to whiteflies. *Pest Manag Sci* (2024).
16 Yan J, Zhang M, Li J, Rondon SI and Gao Y, Synthesis and bioactivity studies of the potato tuber moth, *Phthorimaea operculella* Zeller (Lepidoptera: Gelechiidae) sex pheromone analogs. *Pest Manag Sci* (2024).
17 He M, Long G, Feng H, Zhao Y, Zhou Y, Zhang M *et al*., Crucial role of a takeout protein in white-backed planthopper *Sogatella furcifera* (Horváth) orientation towards its host rice plants. *Pest Manag Sci* (2024).
18 Gandham K, Gautam M, George J, Reddy GVP and Kariyat R, Muffled olfactory and sensory cues from the reproductive stage soybean selectively reduce oviposition of a major polyphagous herbivore, fall armyworm (*Spodoptera frugiperda*). *Pest Manag Sci* (2024).
19 Xu M, Lu C, Wan P, Yin H, Wang L, Liang G *et al*., Oviposition-deterrent activity of *p* -methyl benzaldehyde and 2-hydroxy-5-methoxybenzaldehyde from the extract of *Periplocae cortex* for the control of *Spodoptera frugiperda*. *Pest Manag Sci* (2025).
20 Pereira P, Morales-Silva T, Coelho RS, Pec M, Azevedo KEX, Prado A *et al*., Silicon fertilization in maize increases attractiveness of nocturnal herbivore-induced plant volatiles to *Spodoptera frugiperda* natural enemies. *Pest Manag Sci* (2025).
21 Li F, Liu J, Dewer Y, Ahsan MH and Wu C, Quercetin, a natural flavonoid induced by the spider mite *Tetranychus urticae* or alamethicin, is involved in the defense of lima bean against spider mites. *Pest Manag Sci* (2025).
22 Cook S and Jędryczka M, Integrated pest control in oilseed crops—new advances from the rapeseed research community. *Pest Manag Sci* **80**:2217–2219 (2024).
23 Rüde D, Ulber B, Cook SM and Rostás M, Attraction of cabbage stem flea beetle (*Psylliodes chrysocephala*) to host plant odors. *Pest Manag Sci* (2025).
24 Inward D, Vuts J, Thomas G, Barnard K, Caulfield JC, Powers SJ *et al*., Investigating the threat to Sitka spruce from *Ips typographus*: discrimination and colonization of Britain's principal commercial conifer by a damaging forest pest. *Pest Manag Sci* (2025).
25 Zhang X and Wang G, Sources, identification, and behavioral significance of oviposition-deterring pheromones in insects. *Pest Manag Sci* (2025).
26 Tobin KN, Peeler AS, Yilmaz A, Baniszewski J, Krawczyk G, Ranger CM *et al*., Evaluating the push-pull strategy in eastern apple orchards: verbenone effectively reduces ambrosia beetle populations without the need for a pull factor in a species-specific manner. *Pest Manag Sci* (2025).
27 Marrone PG, Status of the biopesticide market and prospects for new bioherbicides. *Pest Manag Sci* **80**:81–86 (2024).