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EDITORIAL

Special issue on recent advances in zoophytophagous arthropods for agroecosystems sustainability

Alberto Urbaneja[1] · Moshe Coll[2] · Josep A. Jaques[3] · Jose Eduardo Serrao[4] · Dionysios Perdikis[5] · Amy L. Roda[6]

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Zoophytophagous predators (ZP) display an omnivorous behavior and feed on both plants and arthropods (Coll and Guershon 2002). On the one hand, zoophagy allows them to effectively feed on a wide range of prey, including many agricultural pests such as whiteflies, moths, aphids, thrips, or mites. On the other hand, phytophagy allows them to remain and even establish in crops during periods of prey scarcity. These positive traits have led to the inclusion of many species of ZP in sustainable pest management programs for different crops worldwide (van Lenteren et al. 2018). In recent years, the use and conservation of ZP have been extensively promoted, mainly because ZP can sustain themselves on plant-provided materials even when prey is scarce in crop fields. In turn, these ZP may retard recolonization of crop plants by pest species. The trend observed in the greater use of species of ZP has been associated with an increase in the number of new investigations into this important group of natural enemies. The *Journal of Pest Science* has published many advances in this field, and the motivation to launch this special issue arose to continue to deepen scientific knowledge on ZP. This special issue covers the most recent developments in ZP. Fourteen innovative research articles and three reviews are included in this special issue focused of artificial selection on biological and behavioral traits, the capacity of ZP to induce plant defenses, trophic interactions involving ZP at different levels, behavioral aspects of ZP, or strategies to minimize plant damage and/ or maximize their biocontrol services in integrated and organic crop protection programs.

Mirid bugs (Hemiptera: Miridae) are among the most paradigmatic representative ZP. Initially, mirids were mainly used to control whiteflies in greenhouse tomato crops. In recent years, their use has increased in southern Europe for the management of the South America pinworm *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae) (Desneux et al. 2022). The successes achieved with mirids, such as *Macrolophus pygmaeus* (Rambur) and *Nesidiocoris tenuis* (Reuter) (Fig. 1) in Europe, have motivated biocontrol practitioners in other regions to explore native or naturalized mirids for the control not only of these two pests (Roda et al. 2020; van Lenteren et al. 2021) but also of other pests such as the tomato psyllid *Bactericera cockerelli* (Šulc) (Hemiptera: Triozidae) (Pérez-Aguilar et al. 2019).

The best known cases of ZP exploiting their phytophagy in pest management have occurred in horticultural crops with species of the Miridae and Anthocoridae families. However, other ZP [i.e., pentatomids (Hemiptera: Pentatomidae) (Plata-Rueda et al. 2022) and predatory mites (Acari: Phytoseiidae) (Maoz et al. 2011; Cruz-Miralles et al. 2019)] are immerging as important biocontrol agents in other agroecosystems, such as perennial crops.

An attractive added value that phytophagy provides ZP has recently been revealed. When feeding on plants, ZP induce defense mechanisms (both direct and indirect);

✉ Alberto Urbaneja
urbaneja_alb@gva.es

1 Centro de Protección Vegetal y Biotecnología, Instituto Valenciano de Investigaciones Agrarias (IVIA), CV-315, Km 10.7, 46113 Moncada, Valencia, Spain

2 Department of Entomology, Robert H. Smith Faculty of Agriculture, Food and Environment, Hebrew University of Jerusalem, P.O. Box 12, 76100 Rehovot, Israel

3 Departament de Biologia, Bioquímica i Ciències Naturals. Universitat Jaume I, Campus del Riu Sec; Av. Vicent Sos Baynat s/n, 12071 Castelló de Plana, Spain

4 Department of General Biology, Federal University of Viçosa, Viçosa, MG 36570-900, Brazil

5 Laboratory of Agricultural Zoology and Entomology, Department of Crop Science, School of Plant Sciences, Agricultural University of Athens, Iera Odos 75, 118 55 Athens, Greece

6 United States Department of Agriculture, Animal Plant Health Inspection Service, Plant Protection and Quarantine, Science and Technology, Miami, FL 33158, USA

Fig. 1 A female of the zoophytophagous predator *Nesidiocoris tenuis* Reuter with stylets inserted into tomato plant tissue. Photograph credit: Ángel Plata (IVIA)

the response of these plants to ZP feeding is similar to that to harmful herbivores (Pérez-Hedo et al. 2022). This activation makes plants more resilient against the attack of certain pests. Further, ZP activation makes plants more attractive to natural enemies due to the release of herbivore-induced plant volatiles (HIPVs) (Pérez-Hedo et al. 2015). In addition, some HIPVs communicate a warning message to neighboring, uninfested plants ahead of upcoming herbivore attack (Pérez-Hedo et al. 2021a). Upon receiving these warning signals, healthy plants, in turn, activate their own defensive mechanisms. These discoveries, generated from studies with ZP, have developed a new pest management method based on plant-to-plant communication (Pérez-Hedo et al. 2021b).

In recent years, there has been a renewed interest in the genetic improvement in natural enemies to select for desirable traits (Leung et al. 2020). In horticultural crops, it has been possible to improve several traits of interest (i.e., size or suitability of pollen diet) in *Orius laevigatus* Fieber (Hemiptera: Anthocoridae) as well as to increase its tolerance to certain insecticides (Bielza et al. 2020; Mendoza et al. 2021). In stone fruit crops, an isoline with increased zoophagy of the mostly phytozoophagous *Campylomma verbasci* (Meyer) (Hemiptera: Miridae) was achieved through selection (Dumont et al. 2019).

Although ZP have an important role in crop protection, the phytophagy of some species may limit their use as biocontrol agents or, at times, even cause a ZP species to be considered pest (Moerkens et al. 2020). The most controversial species in this respect is *N. tenuis*. Despite its high efficacy against whiteflies and *T. absoluta*, *N. tenuis* may cause severe damage to tomato crops when its densities are high and prey is scarce (Chinchilla-Ramírez et al. 2021). It has recently been observed that phytophagy could be genetically regulated, and selecting for less phytophagous strains is possible (Chinchilla-Ramírez et al. 2020). In addition, earlier ideas, such as using companion plants or adding alternative foods, have been explored to minimize damage caused by *N. tenuis* to the crop (Biondi et al. 2016; Siscaro et al. 2019; Urbaneja-Bernat et al. 2019; Chailleux et al. 2022).

The vegetation composition in the landscape has an important effect on the movement and dispersion of ZP through the agroecosystems (Thomine et al. 2020). In recent years, biodiversity has been encouraged in order to increase sustainability of both protected and open-field cropping systems. As a result, agricultural systems are becoming increasingly more complex and thus have significantly more ecological interactions among the operating species. In the case of ZP, these interactions are even more complicated because they shift their diet between various prey and plants in the landscape. The complexity of these systems calls for the use of more advanced research tools, including molecular techniques (Moreno-Ripoll et al. 2014), and new analytical methods, such as geostatistics, in combination with theoretical modeling studies (Moerkens et al. 2021; Neeson et al. 2013; Schuldiner-Harpaz 2022).

This special issue aims at bringing together the most recent research on these topics related to ZP. Undoubtedly, this special issue contributes significantly to our basic and applied understanding of ZP toward better manage agroecosystem sustainability.

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References

Bielza P, Balanza V, Cifuentes D, Mendoza JE (2020) Challenges facing arthropod biological control: identifying traits for genetic improvement of predators in protected crops. Pest Manag Sci 76:3517–3526. https://doi.org/10.1002/ps.5857

Biondi A, Zappalà L, Di Mauro A et al (2016) Can alternative host plant and prey affect phytophagy and biological control by the zoophytophagous mirid *Nesidiocoris tenuis*? Biocontrol 61:79–90. https://doi.org/10.1007/s10526-015-9700-5

Chailleux A, Ndjiliw S, Diakhaté M et al (2022) Approaches to conservation of *Nesidiocoris tenuis* for biological control of pests in field-grown tomato in Senegal. Biol Control 172:104984. https://doi.org/10.1016/j.biocontrol.2022.104984

Chinchilla-Ramírez M, Garzo E, Fereres A et al (2021) Plant feeding by *Nesidiocoris tenuis*: quantifying its behavioral and mechanical components. Biol Control 152:104402. https://doi.org/10.1016/j.biocontrol.2020.104402

Chinchilla-Ramírez M, Pérez-Hedo M, Pannebakker BA, Urbaneja A (2020) Genetic variation in the feeding behavior of isofemale lines of *Nesidiocoris tenuis*. Insects 11:513. https://doi.org/10.3390/insects11080513

Coll M, Guershon M (2002) Omnivory in terrestrial arthropods: mixing plant and prey diets. Annu Rev Entomol 47:267–297. https://doi.org/10.1146/annurev.ento.47.091201.145209

Cruz-Miralles J, Cabedo-López M, Pérez-Hedo M et al (2019) Zoophytophagous mites can trigger plant-genotype specific defensive responses affecting potential prey beyond predation: the case of *Euseius stipulatus* and *Tetranychus urticae* in citrus. Pest Manag Sci 75:1962–1970. https://doi.org/10.1002/ps.5309

Desneux N, Han P, Mansour R et al (2022) Integrated pest management of *Tuta absoluta*: practical implementations across different world regions. J Pest Sci 95:17–39. https://doi.org/10.1007/s10340-021-01442-8

Dumont F, Réale D, Lucas É (2019) Can isogroup selection of highly zoophagous lines of a zoophytophagous bug improve biocontrol of spider mites in apple orchards? Insects 10:303. https://doi.org/10.3390/insects10090303

Leung K, Ras E, Ferguson KB et al (2020) Next-generation biological control: the need for integrating genetics and genomics. Biol Rev 95:1838–1854. https://doi.org/10.1111/brv.12641

Maoz Y, Gal S, Argov Y et al (2011) Biocontrol of persea mite, *Oligonychus perseae*, with an exotic spider mite predator and an indigenous pollen feeder. Biol Control 59:147–157. https://doi.org/10.1016/j.biocontrol.2011.07.014

Mendoza JE, Balanza V, Cifuentes D, Bielza P (2021) Genetic improvement of *Orius laevigatus* for better fitness feeding on pollen. J Pest Sci 94:729–742. https://doi.org/10.1007/s10340-020-01291-x

Moerkens R, Janssen D, Brenard N et al (2021) Simplified modelling enhances biocontrol decision making in tomato greenhouses for three important pest species. J Pest Sci 94:285–295. https://doi.org/10.1007/s10340-020-01256-0

Moerkens R, Pekas A, Bellinkx S et al (2020) *Nesidiocoris tenuis* as a pest in Northwest Europe: intervention threshold and influence of Pepino mosaic virus. J Appl Entomol 144:566–577. https://doi.org/10.1111/jen.12789

Moreno-Ripoll R, Gabarra R, Symondson WOC et al (2014) Do the interactions among natural enemies compromise the biological control of the whitefly *Bemisia tabaci*? J Pest Sci 87:133–141. https://doi.org/10.1007/s10340-013-0522-x

Neeson TM, Salomon M, Coll M (2013) Nutrient-specific foraging leads to Allee effects and dynamic functional responses. Oikos 122(2):265–273. https://doi.org/10.1111/j.1600-0706.2012.20256.x

Pérez-Aguilar DA, Martínez AM, Viñuela E et al (2019) Impact of the zoophytophagous predator *Engytatus varians* (Hemiptera: Miridae) on *Bactericera cockerelli* (Hemiptera: Triozidae) control. Biol Control 132:29–35. https://doi.org/10.1016/j.biocontrol.2018.12.009

Pérez-Hedo M, Alonso-Valiente M, Vacas S et al (2021a) Eliciting tomato plant defenses by exposure to herbivore induced plant volatiles. Entomol Gen 41:209–218. https://doi.org/10.1127/entomologia/2021/1196

Pérez-Hedo M, Alonso-Valiente M, Vacas S et al (2021b) Plant exposure to herbivore-induced plant volatiles: a sustainable approach through eliciting plant defenses. J Pest Sci 94:1221–1235. https://doi.org/10.1007/s10340-021-01334-x

Pérez-Hedo M, Bouagga S, Zhang NX et al (2022) Induction of plant defenses: the added value of zoophytophagous predators. J Pest Sci in Press. https://doi.org/10.1007/s10340-022-01506-3

Pérez-Hedo M, Urbaneja-Bernat P, Jaques JA et al (2015) Defensive plant responses induced by *Nesidiocoris tenuis* (Hemiptera: Miridae) on tomato plants. J Pest Sci 88:543–554. https://doi.org/10.1007/s10340-014-0640-0

Plata-Rueda A, Martínez LC, Zanuncio JC, Serrão JE (2022) Advances zoophytophagous stinkbugs (Pentatomidae) use in agroecosystems: biology, feeding behavior and biological control. J Pest Sci. https://doi.org/10.1007/s10340-022-01518-z

Roda A, Castillo J, Allen C et al (2020) Biological control potential and drawbacks of three zoophytophagous mirid predators against *Bemisia tabaci* in the United States. Insects 11:670. https://doi.org/10.3390/insects11100670

Schuldiner-Harpaz T, Coll M, Wajnberg E (2022) Optimal foraging strategy to balance mixed diet by generalistconsumers: a simulation model. Behaviour 1(aop):1–22. https://doi.org/10.1163/1568539X-bja10178

Siscaro G, Lo Pumo C, Tropea Garzia G et al (2019) Temperature and tomato variety influence the development and the plant damage induced by the zoophytophagous mirid bug *Nesidiocoris tenuis*. J Pest Sci 92:1049–1056. https://doi.org/10.1007/s10340-019-01096-7

Thomine E, Jeavons E, Rusch A et al (2020) Effect of crop diversity on predation activity and population dynamics of the mirid predator *Nesidiocoris tenuis*. J Pest Sci 93:1255–1265. https://doi.org/10.1007/s10340-020-01222-w

Urbaneja-Bernat P, Bru P, González-Cabrera J et al (2019) Reduced phytophagy in sugar-provisioned mirids. J Pest Sci 92:1139–1148. https://doi.org/10.1007/s10340-019-01105-9

van Lenteren JC, Bolckmans K, Köhl J et al (2018) Biological control using invertebrates and microorganisms: plenty of new opportunities. Biocontrol 63:39–59. https://doi.org/10.1007/s10526-017-9801-4

van Lenteren JC, Lanzoni A, Hemerik L et al (2021) The pest kill rate of thirteen natural enemies as aggregate evaluation criterion of their biological control potential of *Tuta absoluta*. Sci Rep 11:10756. https://doi.org/10.1038/s41598-021-90034-8