Advances in Entomology, 2017, 5, 115-126
http://www.scirp.org/journal/ae
ISSN Online: 2331-2017
ISSN Print: 2331-1991

Ecology and Role of the Rove Beetle, *Dalotia coriaria*, and Insidious Flower Bug, *Orius insidiosus*, in Greenhouse Biological Control Programs

Raymond A. Cloyd*, Nathan J. Herrick

Department of Entomology, Kansas State University, Manhattan, KS, USA
Email: *rcloyd@ksu.edu

How to cite this paper: Cloyd, R.A. and Herrick, N.J. (2017) Ecology and Role of the Rove Beetle, *Dalotia coriaria*, and Insidious Flower Bug, *Orius insidiosus*, in Greenhouse Biological Control Programs. *Advances in Entomology*, **5**, 115-126.
https://doi.org/10.4236/ae.2017.54012

Received: July 6, 2017
Accepted: August 7, 2017
Published: August 10, 2017

Abstract

Greenhouse production systems typically involve growing multiple crop types simultaneously, including ornamentals and vegetables. Therefore, greenhouse producers commonly deal with multiple pest complexes. Two important insect pests of greenhouse-grown horticultural crops are fungus gnats (*Bradysia* spp.) and western flower thrips (*Frankliniella occidentalis*). A plant protection strategy that can be used to manage both pests is biological control. The rove beetle (*Dalotia coriaria*) and insidious flower bug (*Orius insidiosus*) are generalist predators commercially available for use in greenhouse production systems targeting fungus gnats and the western flower thrips. This article describes the biology, behavior, ecology, and role of both natural enemies in greenhouse production systems, and discusses the direct and indirect effects of pesticides (insecticides, miticides, and fungicides) on *D. coriaria* and *O. inisidiosus*.

Keywords

Natural Enemies, Predation, Pesticides, Biological Control, Western Flower Thrips, Fungus Gnat

1. Introduction

A wide-diversity of horticultural crops are grown simultaneously in greenhouse production systems including ornamentals and vegetables [1] [2]. Greenhouse producers strive to maintain plant quality for consumer satisfaction and consequently economic benefits. However, there are challenges associated with growing horticultural crops in greenhouses, such as, dealing with insect and/or mite pests that can reduce aesthetic quality, marketability, and yield of a given crop [3] [4]. Therefore, greenhouse producers must provide inputs related to plant protection strategies in order to protect crops from damage affiliated with insect or mite pests. Furthermore, greenhouse producers typically deal with multiple pest complexes simultaneously [2] [5] [6]. Two major insect pests of greenhouse production systems are fungus gnats, *Bradysia* spp., (Diptera: Sciaridae), and western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae). Both insect pests can cause direct damage by feeding on plant parts and indirect damage by transmitting plant pathogens, including soil-borne fungi and viruses [7]-[14].

A plant protection strategy that can be implemented to manage insect or mite pest populations is biological control. Biological control entails periodic releases of natural enemies or biological control agents, such as parasitoids and predators in order to regulate or maintain insect or mite pest populations below damaging levels [4] [6] [15]. There are natural enemies commercially available for use against fungus gnats and western flower thrips including the following predatory mites: *Stratiolaelaps scimitus* (Womersley) (formerly = "*Hypoaspis miles*") (Acari: Laelapidae) [16] [17], *Neoseiulus* (formerly = *Amblyseius*) *cucumeris* Oudemans (Acari: Phytoseiidae) [18] [19] [20], and *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae) [21] [22]. In addition, two generalist predators commercially available for use in greenhouse production systems are the rove beetle, *Dalotia coriaria* (Kraatz) (Coleoptera: Staphylinidae), and the insidious flower bug, *Orius insidiosus* (Say) (Hemiptera: Anthocoridae).

2. Rove Beetle (*Dalotia coriaria*)

Dalotia (formerly = *Atheta*) *coriaria* adults are glossy, dark-brown, covered with a thick pubescence, and approximately 3 to 4 mm long [23]. Adults begin searching for food after emerging from pupae, and are mobile, flying long distances although they tend to spend most of their time in growing media. Larvae are white during the early instars whereas the later instars are yellow-brown [24]. The life history of *D. coriaria* has been studied under laboratory conditions with development time from egg to adult taking 17 days [25] although development time varies depending on temperature. For instance, development time from egg to adult is 21 to 22 days at 25˚C and 11 to 12 days at 30˚C [23]. Additional life history parameters that have been investigated include the following: egg, larval, and pupal development; male and female longevity; female fecundity; and number of adults per female in the F1 generation [25]. Adult longevity may influence effectiveness of *D. coriaria* when used as a biological control agent because adults prey and lay eggs for extended time periods, which may enhance their ability to regulate fungus gnat larval populations in greenhouses [25]. *Dalotia coriaria* is easy to rear under laboratory conditions using either live prey (fungus gnat larvae) or artificial diets, such as ground trout pellets, turkey starter crumbs, and/or oats, *Avena sativa* L. [25] [26]. In addition, greenhouse producers in the UK have experimented with "breeding boxes" or rearing-release boxes to establish populations of *D. coriaria* in poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch) and cyclamen (*Cyclamen persicum* Mill.) crops [27]. However, cannibalism may occur under crowded conditions when rearing *D. coriaria* [23].

Adults and larvae reside in the growing medium and feed on fungus gnat larvae [24] [28] [29] and western flower thrips pupae (Yinping Li, unpublished data). Rove beetle adults prefer fungus gnat, *Bradysia* sp. nr. *coprophila* (Lintner) larvae over oats in choice tests conducted under laboratory conditions [30]. However, rove beetle larvae do not develop into pupae in the absence of prey [23]. Total prey consumption of fungus gnat larvae by rove beetle adults increases as the number of rove beetle adults increases, reaching a maximum at four adult rove beetles per 473 mL deli container [29]. However, five rove beetle adults per 473 mL container were not effective in suppressing fungus gnat larval populations (20 fungus gnat larvae per 473 mL container) [31]. *Dalotia coriaria* can also feed on the eggs and first instar larvae of *Duponchelia fovealis* Zeller (Lepidoptera: Pyralidae) [32]. Since *D. coriaria* feeds on a wide-range of prey, the predator may be able to switch from preferred prey to non-preferred prey depending on changes in abundance [23]. Moreover, the ability of rove beetle adults to effectively regulate fungus gnat larval populations can be influenced by cultural practices, such as, growing medium type and watering practices [33]. Greenhouse producers throughout the USA are successfully using *D. coriaria* against fungus gnats (R. A. Cloyd; personal observation).

3. Insidious Flower Bug (*Orius insidiosus*)

Orius insidiosus adults are black, 2 to 5 mm in length, and flattened with distinctively patterned black and white wings. Eggs are laid inside plant tissues and nymphs that emerge from eggs are light-brown [34]. Plant suitability may influence egg-laying by females, which may be affiliated with plant nutritional quality [35]. Under laboratory conditions, mean longevity of *O. insidiosus* females is 26.1 days [36]. *Orius insidiosus* is widely used to regulate pest populations in greenhouse production systems associated with ornamentals and vegetables [37] [38] [39] and is relatively easy to mass produce [39] [40].

The insidious flower bug is a generalist predator. The nymphs and adults feed on a wide-range of arthropod pests including: thrips, whiteflies, aphids, and spider mites [41] [42]. Moreover, *O. insidiosus* can regulate populations of western flower thrips and the two spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), when these pests are present simultaneously [43]. *Orius insidiosus* will also feed on plant sap and pollen in the absence of prey [41] [42]. The insidious flower bug feeds on the larval and adult stages of western flower thrips [42] [44] [45] [46] located on plant leaves and flowers. *Orius insidiosus* can consume more than 20 western flower thrips per day [47]. The insidious flower bug is an effective natural enemy against western flower thrips, either individually or when combined with other natural enemies [48] [49] [50]. A major benefit of releasing *O. insidiosus* instead of the predatory mites, *N. cucumeris* and *A. swirskii*, is that the nymphs and adults of *O. insidiosus* feed on the mobile life stages (larvae and adults) of western flower thrips [45], whereas the predatory mites primarily feed on the 1st instars of western flower thrips [18] [51] [52]. *Orius insidiosus* can effectively regulate populations of western flower thrips in ornamental and vegetable production systems [38] [45] [53].

During winter in the northern portions of the USA, the insidious flower bug undergoes reproductive diapause in response to short (<12 hours) photoperiods [54], which impacts the ability of the predatory bug to effectively regulate western flower thrips populations from September through March [55]. However, extending the photoperiod (≥12 hours of light) and increasing temperature (30˚C) can inhibit *O. insidiosus* from entering diapause [54] [56]. In addition, diapause can be prevented by exposing *O. insidiosus* to an extended photoperiod with blue light (400 - 500 nm) [55].

Banker plant systems consist of non-crop plants that provide alternative food sources (prey) for predators as well as pollen and nectar in order to enhance establishment [57] [58]. "Black Pearl" pepper (*Capsicum annuum* L. "Black Pearl") plants provide sufficient pollen that enhances development, fitness, and abundance of *O. insidiosus* adults [59]. However, "Purple Flash" pepper plants have the highest population growth of *O. insidiosus* and may be a more suitable banker plant in commercial greenhouses [60]. The use of banker plants may improve the effectiveness of *O. insidiosus* in biological control programs designed to regulate western flower thrips populations [57] [58].

Plants may influence the ability of predators to sufficiently regulate pest populations [61] [62] [63] [64]. For instance, *O. insidiosus* does not establish on tomato (*Solanum lycopersicum* L.) plants resulting in minimal regulation of western flower thrips populations [65]. The reason for this may be associated with inadequate functional and numerical responses possibly due to searching behavior hindered by glandular trichomes (hairs) on the leaves and stems of tomato plants [66], which would reduce the ability of *O. insidiosus* to effectively regulate pest populations.

4. Integration in Greenhouse Production Systems

Since *D. coriaria* and *O. insidiosus* feed on different insect pests located either above-ground (western flower thrips) or below-ground (fungus gnats) there are opportunities to use both natural enemies together without the potential of intraguild predation [67] [68]. Both above and below-ground natural enemies may be used simultaneously to regulate populations of one insect pest [69] [70] [71] or even two different insect pests. However, no studies have been conducted to assess the potential of integrating two natural enemies that feed on different insect pests, such as, *D. coriaria* and *O. insidiosus* in greenhouse biological control programs. Research in this area may prove to be invaluable to greenhouse producers in regards to improving biological control programs designed to deal with multiple pest complexes.

5. Effects of Pesticides on *Dalotia coriaria* and *Orius insidiosus*

The use of pesticides, including insecticides, miticides, and fungicides, is a common practice in greenhouse production systems to suppress insect and/or mite populations, and protect plants from plant-pathogenic fungi [72]. Therefore, pesticides may directly or indirectly affect natural enemies; thus potentially disrupting biological control programs and pest suppression. Studies have evaluated the direct and/or indirect effects of pesticides on *O. insidiosus* [73] [74] [75] [76] and *D. coriaria* [28] [77] [78].

The interactions associated with integrating pesticides with natural enemies are more complex when using multiple natural enemies to regulate different insect and/or mite pest populations [79]. However, pesticide exposure may not directly or indirectly affect a natural enemy such as *O. insidiosus* inhabiting aboveground plant parts (e.g., leaves, stems, or flowers). Nonetheless, excess solution ("run-off") from foliar spray applications may directly or indirectly affect a natural enemy residing in the growing medium like *D. coriaria*, thus compromising biological control programs targeting another insect pest [78].

A number of pesticides are not directly harmful to rove beetle adults including: fungicides (azoxystrobin, fosetyl-aluminum, and mefenoxam), *Bacillus thuringiensis* subsp. *israelensis*, flonicamid, *Metarhizium anisopliae*, azadirachtin, and spinosad [77]. Furthermore, none of the pesticides impeded predation of rove beetle adults on fungus gnat (*Bradysia* sp. nr. *coprophila*) larvae. However, the pesticides clothianidin, dinotefuran, imidacloprid, chlorpyrifos, and chlorfenapyr are directly harmful to rove beetle adults. A follow-up study [78] reported that certain pesticides were directly harmful to rove beetle adults including: acetamiprid, lambda-cyhalothrin, and cyfluthrin whereas other pesticides such as, *Beauveria bassiana*, azadirachtin, and organic oils (cinnamon oils, rosemary oil, thyme oil, and clove oil) were not directly harmful to adult rove beetles.

A comprehensive study evaluated the effects (direct and indirect) of pesticides on *O. insidiosus* adults under laboratory conditions [76]. The findings indicated that fungicides (aluminum tris, azoxystrobin, fenhexamid, and kresoxim-methyl), insect growth regulators (azadirachtin, buprofezin, kinoprene, and pyriproxyfen), botanicals (*Capsicum oleoresin* extract, garlic oil, soybean oil; and rosemary, rosemary oil, peppermint oil, and cottonseed oil), and entomopathogenic fungi (*Beauveria bassiana* and *Metarhizium anisopliae*) are not directly harmful to *O. insidiosus* with 80% to 100% adult survival. However, the pesticides abamectin, spinosad, pyridalyl, chlorfenapyr, tau-fluvalinate, imidacloprid, dinotefuran, acetamiprid, and thiamethoxam were directly harmful to *O. insidiosus* after 96 hours (0% to 60% adult survival). Nevertheless, none of the pesticides indirectly affected predation of surviving adult *O. insidiosus* on western flower thrips adults [76].

The fungicides myclobutanil and potassium bicarbonate are not directly harmful to *O. insidiosus* adults [80]. So, fungicides may be used in conjunction with both natural enemies. Insect growth regulators are presumed to have no direct or indirect effects on the adult stage of natural enemies since insect growth regulators are only active on the immature stage [72] [81]. Studies [77] [78] [82] support the presumption that insect growth regulators (e.g., azadirachtin, buprofezin, kinoprene, and pyriproxyfen), in general, are not directly or indirectly harmful to either natural enemy under laboratory conditions. In addition, the insect growth regulators, cyromazine, diflubenzuron, and novaluron are not directly harmful to *D. coriaria* adults after 96 hours of exposure [28]. Furthermore, entomopathogenic fungi including *Beauveria bassiana* and *Metarhizium anisopliae* are not directly harmful to *D. coriaria* and *O. insidiosus* [76] [77]. Therefore, the pesticide types described above may be integrated into plant protection programs for western flower thrips and fungus gnats that include *D. coriaria* and *O. insidiosus*. Furthermore, the pesticide mixture (combination of two active ingredients) of azadirachtin + *B. bassiana* is not directly harmful to *D. coriaria* and *O. insidiosus* [76].

Dalotia coriaria and *O. insidiosus* are commercially available generalist predators that can effectively regulate populations of fungus gnats and western flower thrips. Therefore, greenhouse producers should consider releasing these natural enemies in greenhouse production systems in order to reduce inputs from pesticides and diminish the potential for resistance developing in pest populations.

Acknowledgements

The authors would like to thank Dr. Mary Beth Kirkham from the Department of Agronomy at Kansas State University (Manhattan, KS) for reviewing an initial draft of the manuscript.

References

[1] Parrella, M.P. (1999) Arthropod Fauna. In: Stanhill, G. and Zvi Enoch, H., Eds., *Ecosystems of the World* 20. *Greenhouse Ecosystems*, Elsevier, New York, NY, 213-250.

[2] Cloyd, R.A. (2016) Greenhouse Pest Management. CRC Press (Taylor & Francis Group), Boca Raton, FL. https://doi.org/10.1201/b20277

[3] Osborne, L.S. and Oetting, R.D. (1989) Biological Control of Pests Attacking Greenhouse Grown Ornamentals. *Florida Entomologist*, **72**, 408-413. https://doi.org/10.2307/3495175

[4] Cloyd, R.A. (2012) Chapter 13: Insect and Mite Management in Greenhouses. In: Nelson, P.V., Ed., *Greenhouse Operation and Management*, 7th Edition, Pearson Prentice Hall, Upper Saddle River, NJ, 391-414.

[5] Van Driesche, R.G. and Heinz, K.M. (2004) Biological Control as a Component of

IPM Systems. In: Heinz, K.M., Van Driesche, R.G. and Parrella, M.P., Eds., *Biocontrol in Protected Culture*, Ball Publishing, Batavia, IL, 25-36.

[6] Gigon, V., Camps, C. and Le Corff, J. (2016) Biological Control of *Tetranychus urticae* by *Phytoseiulus macropilis* and *Macrolophus pygmaeus* in Tomato Greenhouses. *Experimental and Applied Acarology*, **68**, 55-70. https://doi.org/10.1007/s10493-015-9976-2

[7] Wilkinson, J.D. and Daugherty, D.M. (1970) The Biology and Immature Stages of *Bradysia impatiens* (Diptera: Sciaridae). *Annuals of the Entomological Society of America*, **63**, 656-660. https://doi.org/10.1093/aesa/63.3.656

[8] Chisholm, I.F. and Lewis, T. (1984) A New Look at Thrips (Thysanoptera) Mouthparts, Their Action and Effects of Feeding on Plant Tissue. *Bulletin of Entomological Research*, **74**, 663-675. https://doi.org/10.1017/S0007485300014048

[9] Gardiner, R.B., Jarvis, W.R. and Shipp, J.K. (1990) Ingestion of *Pythium* spp. by Larvae of Fungus Gnat *Bradysia impatiens* (Diptera: Sciaridae). *Annals of Applied Biology*, **116**, 205-212. https://doi.org/10.1111/j.1744-7348.1990.tb06600.x

[10] Tommasini, M.G. and Maini, S. (1995) *Frankliniella occidentalis* and Thrips Harmful to Vegetable and Ornamental Crops in Europe. In: Loomans, A.J.M., van Lenteren, J.C., Tommasini, S., Maini, S. and Riudavets, J., Eds., *Biological Control of Thrips Pests*, Agric. Univ. Papers, Wageningen, 1-42.

[11] Childers, C.C. and Achor, D.S. (1995) Thrips Feeding and Oviposition Injuries to Economic Plants, Subsequent Damage and Host Responses to Infestation. In: Parker, B.L., Skinner, M. and Lewis, T., Eds., *Thrips Biology and Management*, Plenum Press, New York, 31-52. https://doi.org/10.1007/978-1-4899-1409-5_3

[12] Daughtrey, M.L., Jones, R.K., Moyer, J.W., Daub, M.E. and Baker, J.R. (1997) Tospoviruses Strike the Greenhouse Industry. *Plant Disease*, **81**, 1220-1230. https://doi.org/10.1094/PDIS.1997.81.11.1220

[13] El-Hamalawi, Z.A. (2008) Acquisition, Retention and Dispersal of Soilborne Plant Pathogenic Fungi by Fungus Gnats and Moth Flies. *Annals of Applied Biology*, **153**, 195-203. https://doi.org/10.1111/j.1744-7348.2008.00247.x

[14] Pappu, H.R., Jones, R.A.C. and Jain, R.K. (2009) Global Status of Tospovirus Epidemics in Diverse Cropping Systems: Success Achieved and Challenges Ahead. *Virus Research*, **141**, 219-236. https://doi.org/10.1016/j.virusres.2009.01.009

[15] van Lenteren, J.C. (2012) The State of Commercial Augmentative Biological Control: Plenty of Natural Enemies, but a Frustrating Lack of Uptake. *BioControl*, **57**, 1-20. https://doi.org/10.1007/s10526-011-9395-1

[16] Chambers, R.J., Wright, E.M. and Lind, R.J. (1993) Biological Control of Glasshouse Sciarid Flies (*Bradysia spp.*) with the Predatory Mite, *Hypoaspis miles*, on Cyclamen and Poinsettia. *Biocontrol Science and Technology*, **3**, 285-293. https://doi.org/10.1080/09583159309355283

[17] Wright, E.M. and Chambers, R.J. (1994) The Biology of the Predatory Mite *Hypoaspis miles* (Acari: Laelapidae), a Potential Biological Control Agent of *Bradysia paupera* (Dipt.: Sciaridae). *Entomophaga*, **39**, 225-235. https://doi.org/10.1007/BF02372360

[18] Gillespie, D.R. (1989) Biological Control of Thrips (Thysanoptera: Thripidae) on Greenhouse Cucumber by *Amblyseius cucumeris*. *Entomophaga*, **34**, 185-192. https://doi.org/10.1007/BF02372667

[19] De Courcy Williams, M.E. (2011) Biological Control of Thrips on Ornamental Crops: Interactions between the Predatory Mite *Neoseiulus cucumeris* (Acari: Phytoseiidae) and Western Flower Thrips, *Franklinella occidentalis* (Thysanoptera:

Thripidae), on Cyclamen. *Biocontrol Science and Technology*, **11**, 41-55. https://doi.org/10.1080/09583150020029736

[20] Manners, A.G., Dembowski, B.R. and Healey, M.A. (2013) Biological Control of Western Flower Thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae), in Gerberas, Chrysanthemums and Roses. *Australian Journal of Entomology*, **52**, 246-258. https://doi.org/10.1111/aen.12020

[21] Messelink, G.J., van Steenpaal, S.E.F. and Ramakers, P.M.J. (2006) Evaluation of Phytoseiid Predators for Control of Western Flower Thrips on Greenhouse Cucumber. *BioControl*, **51**, 753-768. https://doi.org/10.1007/s10526-006-9013-9

[22] Calvo, F.J., Bolckmans, K. and Belda, J.E. (2011) Control of *Bemisia tabaci* and *Frankliniella occidentalis* in Cucumber by *Amblyseius swirskii*. *BioControl*, **56**, 185-192. https://doi.org/10.1007/s10526-010-9319-5

[23] Miller, K.V. and Williams, R.N. (1983) Biology and Host Preference of *Atheta coriaria* (Coleoptera: Staphylinidae), an Egg Predator of Nitidulidae and Muscidae. *Annals of the Entomological Society of America*, **76**, 158-161. https://doi.org/10.1093/aesa/76.2.158

[24] Helyer, N., Cattlin, N.D. and Brown, K.C. (2014) Biological Control in Plant Protection: A Color Handbook. 2nd Edition, CRC Press (Taylor &Francis Group), Boca Raton, Florida. https://doi.org/10.1201/b16042

[25] Echegaray, E.R. and Cloyd, R.A. (2013) Life History Characteristics of the Rove Beetle, *Dalotia coriaria* (Coleoptera: Staphylinidae) under Laboratory Conditions. *Journal of the Kansas Entomological Society*, **86**, 145-154. https://doi.org/10.2317/JKES120927.1

[26] Carney, V.A., Diamond, J.C., Murphy, G.D. and Marshall, D. (2002) The Potential of *Atheta coriaria* Kraatz (Coleoptera: Staphylinidae), as a Biological Control Agent for Use in Greenhouse Crops. *International Organization for Biological and Integrated Control of Noxious Animals and Plants/ West Palaearctic Regional Section* (*IOBC/ WPRS*) *Bulletin*, **25**, 37-40.

[27] Bennison, J., Maulden, K., Maher, H. and Tomiezek, M. (2008) Development of a Grower Rearing-Release System for *Atheta coriaria*, for Low Cost Biological Control of Ground-Dwelling Pest Life Stages. *International Organization for Biological and Integrated Control of Noxious Animals and Plants/West Palaearctic Regional Section (IOBC/WPRS) Bulletin*, **32**, 21-24.

[28] Jandricic, S., Scott-Dupree, C.D., Broadbent, A.B., Harris, C.R. and Murphy, G. (2006) Compatibility of *Atheta coriaria* with Other Biological Control Agents and Reduced-Risk Insecticides Used in Greenhouse Floriculture Integrated Pest Management Programs for Fungus Gnats. *The Canadian Entomologist*, **138**, 712-722. https://doi.org/10.4039/n05-106

[29] Echegaray, E.A., Cloyd, R.A. and Nechols, J.R. (2015) Rove Beetle (Coleoptera: Staphylinidae) Predation on *Bradysia* sp. nr. *coprophila* (Diptera: Sciaridae). *Journal of Entomological Science*, **50**, 225-237. https://doi.org/10.18474/JES14-38.1

[30] Birken, E.M. and Cloyd, R.A. (2007) Food Preference of the Rove Beetle, *Atheta coriaria* Kraatz (Coleoptera: Staphylinidae) under Laboratory Conditions. *Insect Science*, **14**, 53-56. https://doi.org/10.1111/j.1744-7917.2007.00125.x

[31] Cloyd, R.A. and Chiasson, H. (2007) Activity of an Essential Oil Derived from *Chenopodium ambrosioides* on Greenhouse Insect Pests. *Journal of Economic Entomology*, **100**, 459-466. https://doi.org/10.1093/jee/100.2.459

[32] Messelink, G. and Van Wensveen, W. (2003) Biocontrol of *Duponchelia fovealis* (Lepidoptera: Pyralidae) with Soil-Dwelling Predators in Potted Plants. *Communi-*

cations in Agricultural and Applied Biological Sciences Gent University, **68**, 159-165.

[33] Herrick, N.J. and Cloyd, R.A. (2017) Effects of Growing Medium Type and Moisture Level on Predation by Adult Rove Beetle, *Dalotia coriaria* (Coleoptera: Staphylinidae), on Fungus Gnat, *Bradysia* sp. nr.*coprophila* (Diptera: Sciaridae), Larvae under Laboratory and Greenhouse Conditions. *HortScience*, **52**, 736-741. https://doi.org/10.21273/HORTSCI11842-17

[34] Mahr, S.E.R., Cloyd, R.A., Mahr, D.L. and Sadof, C.S. (2001) Biological Control of Insects and Other Pests of Greenhouse Crops. North Central Regional Publication 581, University of Wisconsin, Madison, WI.

[35] Seagraves, M.P. and Lundgren, J.G. (2010) Oviposition Response by *Orius insidiosus* (Hemiptera: Anthocoridae) to Plant Quality and Prey Availability. *Biological Control*, **55**, 174-177. https://doi.org/10.1016/j.biocontrol.2010.06.013

[36] van de Viere, M. and Degheele, D. (1995) Comparative Laboratory Experiment with *Orius insidiosus* and *Orius albidipennis* (Het.: Anthocoridae), Two Candidates for Biological Control in Glasshouses. *Entomophaga*, **40**, 341-344. https://doi.org/10.1007/BF02373721

[37] Dissevelt, M., Altena, K. and Ravensburg, W.J. (1995) Comparison of Different *Orius* Species for Control of *Frankliniella occidentalis* in Glasshouse Vegetable Crops in the Netherlands. *Mededelingen-Faculteit Landbouwkundige en Toegepaste Biologische Wetenschappen*, *Universiteit Gent*, **60**, 839-845.

[38] Ramachandran, S., Funderburk, J., Stavisky, J. and Olson, S. (2001) Population Abundance and Movement of *Frankliniella* Species and *Orius insidiosus* in Field Pepper. *Agricultural and Forest Entomology*, **3**, 129-137. https://doi.org/10.1046/j.1461-9563.2001.00097.x

[39] Silveira, L.C.P., Bueno, V.H.P. and van Lenteren, J.C. (2004) *Orius insidiosus* as Biological Control Agent for Thrips in Greenhouse Chrysanthemums in the Tropics. *Bulletin of Insectology*, **57**, 1-7.

[40] Ramakers, P.M.J. and van den Meiracker, R.A.F. (1992) Biological Control of Western Flower Thrips with Predatory Mites and Pirate Bugs: Can Two Do Better than One? *Annual Report* 1991, Institute of Plant Protection, Wageningen, 9-21.

[41] Barber, G.W. (1936) *Orius insidiosus* (Say), an Important Natural Enemy of the Corn Earworm. United States Department of Agriculture Technical Bulletin, Washington DC, 504 p.

[42] Kiman, Z.B. and Yeargan, K.V. (1985) Development and Reproduction of the Predator *Orius insidiosus* (Hemiptera: Anthocoridae) Reared on Diets of Selected Plant Material and Arthropod Prey. *Annals of the Entomological Society of America*, **78**, 464-467. https://doi.org/10.1093/aesa/78.4.464

[43] Xu, X., Borgemeister, C. and Poehling, H.-M. (2006) Interactions in the Biological Control of Western Flower Thrips *Frankliniella occidentalis* (Pergande) and Two-Spotted Spider Mite *Tetranychus urticae* Koch by the Predatory Bug *Orius insidiosus* Say on Beans. *Biological Control*, **36**, 57-64. https://doi.org/10.1016/j.biocontrol.2005.07.019

[44] Isenhour, D.J. and Yeargan, K.V. (1981) Predation by *Orius insidiosus* on the Soybean Thrips, *Sericothrips variabilis*: Effect of Prey Stage and Density. *Environmental Entomology*, **10**, 496-500. https://doi.org/10.1093/ee/10.4.496

[45] van den Meiracker, R.A.F. and Ramakers, P.M.J. (1991) Biological Control of the Western Flower Thrips *Frankliniella occidentalis* in Sweet Pepper with the Anthocorid Predator *Orius insidiosus*. *Mededelingen-Faculteit Landbouwkundige en*

Toegepaste Biologische Wetenschappen, *Universiteit Gent*, **56**, 241-249.

[46] Baez, I., Reitz, S.R. and Funderburk, J.E. (2004) Predation of *Orius insidiosus* (Heteroptera: Anthocoridae) on Species and Life Stages of *Frankliniella* Flower Thrips (Thysanoptera: Thripidae) in Pepper Flowers. *Environmental Entomology*, **33**, 662-670. https://doi.org/10.1603/0046-225X-33.3.662

[47] Tommasini, M.G., van Lenteren, J.C. and Burgio, G. (2004) Biological Traits and Predation Capacity of Four *Orius* Species on Two Prey Species. *Bulletin of Insectology*, **57**, 79-93.

[48] Fransen, J.J. and Tolsma, J. (1992) Releases of the Minute Pirate Bug, *Orius insidiosus* (Say) (Hemiptera: Anthocoridae), Against Western Flower Thrips, *Frankliniella occidentalis* (Pergande) on Chrysanthemum. *Mededelingen-Faculteit Landbouwkundige en Toegepaste Biologische Wetenschappen*, *Universiteit Gent*, **57**, 479-484.

[49] Chow, A., Chau, A. and Heinz, K.M. (2008) Compatibility of *Orius insidiosus* (Hemiptera: Anthocoridae) with *Amblyseius* (*Iphiseius*) *degenerans* (Acari: Phytoseiidae) for Control of *Frankliniella occidentalis* (Thysanoptera: Thripidae) on Greenhouse Rose. *Biological Control*, **44**, 259-270. https://doi.org/10.1016/j.biocontrol.2007.11.002

[50] Funderburk, J., Stavisky, J. and Olson, S. (2000) Predation of *Frankliniella occidentalis* (Thysanoptera: Thripidae) in Field Peppers by *Orius insidiosus* (Hemiptera: Anthocoridae). *Environmental Entomology*, **29**, 376-382. https://doi.org/10.1093/ee/29.2.376

[51] van Maanen, R. and Janssen, A. (2008) Prey Preference of the Generalist Predator *Amblyseius swirskii*. *International Organization for Biological and Integrated Control of Noxious Animals and Plants*/ *West Palaearctic Regional Section* (*IOBC*/ *WPRS*) *Bulletin*, **32**, 241-244.

[52] Xu, X. and Enkegaard, A. (2010) Prey Preference of the Predatory Mite, *Amblyseius swirskii* between First Instar Western Flower Thrips *Frankliniella occidentalis* and Nymphs of the Two Spotted Spider Mite *Tetranychus urticae*. *Journal of Insect Science*, **10**, 1-11. https://doi.org/10.1673/031.010.14109

[53] Fransen, J.J., Boogaard, M. and Tolsma, J. (1993) The Minute Pirate Bug, *Orius insidiosus* (Say) (Hemiptera: Anthocoridae), as a Predator of Western Flower Thrips, *Frankliniella occidentalis* (Pergande), in Chrysanthemum, Rose, and *Saintpaulia*. *International Organization for Biological and Integrated Control of Noxious Animals and Plants*/ *West Palaearctic Regional Section* (*IOBC*/ *WPRS*) *Bulletin*, **16**, 73-77.

[54] van den Meiracker, R.A.F. (1994) Induction and Termination of Diapause in *Orius* Predatory Bugs. *Entomologia Experimentalis et Applicata*, **73**, 127-137. https://doi.org/10.1111/j.1570-7458.1994.tb01847.x

[55] Stack, P.A. and Drummond, F.A. (1997) Reproduction and Development of *Orius insidiosus* in a Blue Light-Supplemented Short Photoperiod. *Biological Control*, **9**, 59-65. https://doi.org/10.1006/bcon.1997.0520

[56] Ruberson, J.R., Bush, L. and Kring, T.J. (1991) Photoperiodic Effect on Diapause Induction and Development in the Predator *Orius insidiosus* (Heteroptera: Anthocoridae). *Environmental Entomology*, **20**, 786-789. https://doi.org/10.1093/ee/20.3.786

[57] Frank, S.D. (2010) Biological Control of Arthropod Pests Using Banker Plant Systems: Past, Progress and Future Directions. *Biological Control*, **52**, 8-16. https://doi.org/10.1016/j.biocontrol.2009.09.011

[58] Huang, N., Enkegaard, A., Osborne, L.S., Ramakers, P.M.J., Messelink, G.J., Pijnakker, J. and Murphy, G. (2011) The Banker Plant Method in Biological Control. *Critical Reviews in Plant Sciences*, **30**, 259-278. https://doi.org/10.1080/07352689.2011.572055

[59] Wong, S.K. and Frank, S.D. (2013) Pollen Increases Fitness and Abundance of *Orius insidiosus* Say (Heteroptera: Anthocoridae) on Banker Plants. *Biological Control*, **64**, 45-50. https://doi.org/10.1016/j.biocontrol.2012.09.015

[60] White, M.O., Scott-Dupree, C.D., Brownbridge, M., Buitenhuis, R. and Murphy, G. (2014) Evaluation of Seven Plant Species/Cultivars for Their Suitability as Banker Plants for *Orius insidiosus* (Say). *BioControl*, **59**, 79-87. https://doi.org/10.1007/s10526-013-9549-4

[61] Heinz, K.M. and Zalom, F.G. (1996) Performance of the Predator *Delphastus pusillus* on *Bemisia* Resistant and Susceptible Tomato Lines. *Entomologia Experimentalis et Applicata*, **81**, 345-352. https://doi.org/10.1046/j.1570-7458.1996.00105.x

[62] Scott Brown, A.S., Simmonds, M.S.J. and Blaney, W.M. (1999) Influence of Species of Host Plants on the Predation of Thrips by *Neoseiulus cucumeris*, *Iphiseius degenerans* and *Orius laevigatus*. *Entomologia Experimentalis et Applicata*, **92**, 283-288. https://doi.org/10.1046/j.1570-7458.1999.00548.x

[63] Krips, O.E., Kleijn, P.W., Willems, P.E.L., Gols, G.J.Z. and Dicke, M. (1999) Leaf Hairs Influence Searching Efficiency and Predation Rate of the Predatory Mite *Phytoseiulus persimilis* (Acari: Phytoseiidae). *Experimental and Applied Acarology*, **23**, 119-131. https://doi.org/10.1023/A:1006098410165

[64] Guershon, M. and Gerling, D. (2006) Effects of Plant and Prey Characteristics on the Predatory Behavior of *Delphastus catalinae*. *Entomologia Experimentalis et Applicata*, **121**, 15-21. https://doi.org/10.1111/j.1570-8703.2006.00455.x

[65] Shipp, J.L. and Wang, K. (2003) Evaluation of *Amblyseius cucumeris* (Acari: Phytoseiidae) and *Orius insidiosus* (Hemiptera: Anthocoridae) for Control of *Frankliniella occidentalis* (Thysanoptera: Thripidae) on Greenhouse Tomatoes. *Biological Control*, **28**, 271-281. https://doi.org/10.1016/S1049-9644(03)00091-4

[66] Coll, M. and Ridgway, R.L. (1995) Functional and Numerical Responses of *Orius insidiosus* (Heteroptera: Anthocoridae) to its Prey in Different Vegetable Crops. *Annals of the Entomological Society of America*, **88**, 732-738. https://doi.org/10.1093/aesa/88.6.732

[67] Polis, G.A., Meyers, C.A. and Holt, R.D. (1989) The Ecology and Evolution of Intraguild Predation: Potential Competitors that Eat Each Other. *Annual Review of Ecology, Evolution, and Systematics*, **20**, 297-330. https://doi.org/10.1146/annurev.es.20.110189.001501

[68] Rosenheim, J.A., Kaya, H.K., Ehler, L.E., Marois, J.J. and Jaffee, B.A. (1995) Intraguild Predation among Biological-Control Agents: Theory and Evidence. *Biological Control*, **5**, 303-335. https://doi.org/10.1006/bcon.1995.1038

[69] Losey, J.E. and Denno, R.F. (1998) Positive Predator-Predator Interactions: Enhanced Predation Rates and Synergistic Suppression of Aphid Populations. *Ecology*, **79**, 2143-2152.

[70] Pozzebon, A., Boaria, A. and Dusco, C. (2015) Single and Combined Releases of Biological Control Agents Against Canopy- and Soil-Dwelling Stages of *Frankliniella occidentalis* in Cyclamen. *BioControl*, **60**, 341-350. https://doi.org/10.1007/s10526-014-9641-4

[71] Wu, S., Zhang, Z., Gao, Y., Xu, X. and Lei, Z. (2016) Interactions between Foliage- and Soil-Dwelling Predatory Mites and Consequences for Biological Control of

Frankliniella occidentalis. *BioControl*, **61**, 717-727. https://doi.org/10.1007/s10526-016-9762-z

[72] Cloyd, R.A. (2012) Indirect Effects of Pesticides on Natural Enemies. In: Soundararajan, R.P., Ed., *Pesticides—Advances in Chemical and Botanical Pesticides*, Intech, Rijeka, 127-150. https://doi.org/10.5772/48649

[73] Dinkins, R.L., Brazzel, J.R. and Wilson, C.A. (1971) Effect of Early Season Insecticide Applications on Major Predaceous Arthropods in Cotton Fields under an Integrated Control Program. *Journal of Economic Entomology*, **64**, 480-484. https://doi.org/10.1093/jee/64.2.480

[74] Elzen, G.W. (2001) Lethal and Sublethal Effects of Insecticide Residues on *Orius insidiosus* (Hemiptera: Anthocoridae) and *Geocoris punctipes* (Hemiptera: Lygaeidae). *Journal of Economic Entomology*, **94**, 55-59. https://doi.org/10.1603/0022-0493-94.1.55

[75] Ashley, J.L., Ames Herbert, D., Lewis, E.E., Brewster, C.C. and Huckaba, R. (2006) Toxicity of Three Acaricides to *Tetranychus urticae* (Tetranychidae: Acari) and *Orius insidiosus* (Hemiptera: Anthocordiae). *Journal of Economic Entomology*, **99**, 54-59. https://doi.org/10.1093/jee/99.1.54

[76] Herrick, N.J. and Cloyd, R.A. (2017) Direct and Indirect Effects of Pesticides on the Insidious Flower Bug (Hemiptera: Anthocoridae) under Laboratory Conditions. *Journal of Economic Entomology*, **110**, 931-940. https://doi.org/10.1093/jee/tox093

[77] Cloyd, R.A., Timmons, N.R., Goebel, J.M. and Kemp, K.E. (2009) Effect of Pesticides on Adult Rove Beetle *Atheta coriaria* (Coleoptera: Staphylinidae) Survival in Growing Medium. *Journal of Economic Entomology*, **102**, 1750-1758. https://doi.org/10.1603/029.102.0504

[78] Echegaray, E.R. and Cloyd, R.A. (2012) Effects of Reduced-Risk Pesticides and Plant Growth Regulators on Rove Beetle (Coleoptera: Staphylinidae) Adults. *Journal of Economic Entomology*, **105**, 2097-2106. https://doi.org/10.1603/EC12244

[79] Wawrzynski, R.P., Ascerno, M.E. and McDonough, M.J. (2001) A Survey of Biological Control Users in Midwest Greenhouse Operations. *American Entomologist*, **47**, 228-234. https://doi.org/10.1093/ae/47.4.228

[80] Gradish, A.E., Scott-Dupree, C.D., Shipp, L., Harris. C.R. and Ferguson, G. (2011) Effect of Reduced-Risk Pesticides on Greenhouse Vegetable Arthropod Biological Control Agents. *Pest Management Science*, **67**, 82-86. https://doi.org/10.1002/ps.2036

[81] Tunaz, H. and Uygan, N. (2004) Insect Growth Regulators for Insect Pest Control. *Turkish Journal of Agriculture and Forestry*, **28**, 377-387.

[82] Bostanian, N.J. and Akalach, M. (2006) The Effect of Indoxacarb and Five Other Insecticides on *Phytoseiulus persimilis* (Acari: Phytoseiidae), *Amblyseius fallacis* (Acari: Phytoseiidae) and Nymphs of *Orius insidiosus* (Hemiptera: Anthocoridae). *Pest Management Science*, **62**, 334-339. https://doi.org/10.1002/ps.1171