Acarologia is proudly non-profit, with no page charges and free open access

Please help us maintain this system by encouraging your institutes to subscribe to the print version of the journal and by sending us your high quality research on the Acari.

Subscriptions: Year 2018 (Volume 58): 380 €
http://www1.montpellier.inra.fr/CBGP/acarologia/subscribe.php
Previous volumes (2010-2016): 250 € / year (4 issues)
Acarologia, CBGP, CS 30016, 34988 MONTFERRIER-sur-LEZ Cedex, France

The digitalization of Acarologia papers prior to 2000 was supported by Agropolis Fondation under the reference ID 1500-024 through the « Investissements d’avenir » programme (Labex Agro: ANR-10-LABX-0001-01)

Acarologia is under free license and distributed under the terms of the Creative Commons-BY-NC-ND which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original author and source are credited.
PEST CONTROL BY MITES (ACARI): PRESENT AND FUTURE

Uri Gerson

(Received 17 August 2014; accepted 02 November 2014; published online 19 December 2014)

Department of Entomology, The Robert H. Smith Faculty of Agriculture, Food and Environment, The Hebrew University of Jerusalem, Rehovot 76100, Israel. gerson@agri.huji.ac.il

ABSTRACT — This essay reviews advances in the systematics of mite families containing members that are acarine biocontrol agents (ABAs), including the Phytoseiidae which have several strains or races. Additions to the roster of mites that affect pests (including weeds and pathogens), and of pests that may be, or are, significantly affected by ABAs, were noted. The various pest-debilitating mechanisms used by ABAs, including predation, parasitism, parasitoidism, parasitic castration, competition as well as reductions in weed and phytopathogenic fungal growth are listed. The affected targets include agricultural, veterinary and medical pests, as well as weeds, nematodes and fungi. The effect of intra-guild predation on the ABAs’ ability to affect pests is discussed, along with other organisms that increase the controlling impact of ABAs. The influence of host plants, including their architecture, leaf surfaces, domatia, pollen, genetically modified plants (GMOs) and volatiles are then reviewed. Then come mite feeding on soil-inhabiting pests and the newly-discovered effects of arbuscular mycorrhizal (AM) fungi. ABA feeding on weeds and on nematodes is briefly discussed next, along with the few known ABA diseases. The effect of plant-protection chemicals are then considered, followed by new techniques for the better implementation of ABAs. These include mass rearing, modes of distribution, long-term maintenance and the application of molecular methods to determine quantitative and qualitative feeding rates. This review ends with suggestions for further research, including more collecting and assaying of ABAs (especially indigenous species), determining the effects of secondary predators and of light regimes in greenhouses, and increasing studies on the role of volatiles of plant and nematode source, and of ABAs as vectors of pest diseases.

KEYWORDS — Biocontrol; Acari; pests; plants

INTRODUCTION

A major recent shift in the practice and science of biological control (BC) has been the decline in relying on imported, exotic BC agents, with a concomitant increase in the use of indigenous natural enemies, whether arthropods or microbial. As van Lenteren (2012) stated, nowadays there is a trend to look first for indigenous BC agents when new exotic pests establish in new regions (e.g. Furtado et al. 2007) as illustrated by the number of natural enemies that were used for the first time in Europe in previous decades. Until 1970, the only two species commercially used in Europe were exotic, and during the following three decades, more new exotics were employed than indigenous species. However, in the last decade this trend has changed and for the first time more indigenous species are being commercialized than exotics.

Whether exotic or indigenous, mites (Acari) figure largely amongst arthropod BC agents, being the second largest taxonomic group (after the Hemiptera) that were used in commercial augmen-
tative BC in the period 1900 to 2010 (van Lenteren 2012). The dominant family of mites used in BC is the Phytoseiidae, along with a few species assignable to other families. Gerson et al. (2003) discussed members of 34 families of acarine biocontrol agents (ABAs) that were shown to reduce the populations of pests (including weeds and pathogens) and/or their injuries. The role of ABAs in greenhouse pest management was discussed by Gerson and Weintraub (2012) and efforts to control phytonematodes with mites were summarized by Gerson (in press).

More information has accumulated since 2003 on several further ABA taxa (Table 1), members of additional mite families that may have potential to affect pest numbers were noted, more pests were affected by ABAs, new relevant technology has been tried and much has been learned about the potential of indigenous predatory or parasitic mites to affect pests. These subjects, illustrated by some examples, are the topics of the present essay.

The importance of identifying and determining the systematic status of the ABAs will be discussed first, followed by notes on their provenance and biology, their interactions with plants (including weeds) and aspects of new methodology. Based on these data, future trends in the use of ABAs will be formulated.

**SOME KEY ELEMENTS ON SYSTEMATICS OF ABAS**

Members of the mesostigmatic family Phytoseiidae, dominant amongst ABAs in pest control (van Lenteren 2012), are the main group being studied. The systematics of their over 2,450 valid members (Demite et al. 2014b) has been proposed (Chant and McMurtry 2007), and more species are being added by collecting in hitherto little canvassed countries (Guanilo et al. 2008; Tixier et al. 2012; Kreiter et al. 2013). Demite et al. (2014a, b) provided a database (available at the website www.lea.esalq.usp.br/phytoseiidae) for all species named at that date, and Hernandes et al. (2012) provided a polytomous key to the world species of the large subgenus Typhlodromus (Anthoseius). (freely available online with other keys at the website (http://www1.montpellier.inra.fr/CBGP/phytoseiidae/index.html)). The application of molecular markers to identify phytoseiids species was used, among others, by Li et al. (2012). Two confounding trends are meanwhile impacting on the understanding and use of these species. The first is the recognition that more than a single taxon may be masquerading within the same species. Beard (1999), Noronha et al. (2003) and Kanouh et al. (2010), among others, argued that the precise status of phytoseiid species may be difficult to determine only with morphological criteria, yet accurate identifications are crucial in BC programs. Molecular methods are thus increasingly being used (Walter and Campbell 2003, and Okassa et al. 2009, among others) to resolve issues like misidentifications and synonymies (Tixier et al. 2006; Tixier et al. 2011, 2012; Bowman and Hoy 2012). The second trend is the realization that some of the common species have strains, or populations, which differ in traits like response to aridity, temperature and (most important) to prey that affect their biocontrol efficacy. Some examples are presented in Table 2.

The relevance of phytoseiid classification to biocontrol was emphasized by McMurtry and Croft (1997), who suggested that different taxa could be placed within four types or categories. Type 1 consists of species that are specialized predators of webbing spider mites essentially of the genus Tetranychus. Type 2 also refers to spider mite predators that also feed on other prey. Type 3 includes generalist predators that also consume for instance pollen, honeydew and fungi, and Type 4 includes species that feed and perform better when fed on pollen than on prey. The possibility that further types may exist, possibly more specialized for certain prey, was validated by Adar et al. (2012), who proposed that the ability to feed on plants be added as a cross type trait of phytoseiid life-style types. More recently McMurtry et al. (2013) formulated a new classification of the lifestyles of phytoseiid mites. The discovery of a phytoseiid whose main food source is the coffee leaf rust fungus (Oliveira et al. 2014), suggests that more life styles may be discovered.
TABLE 1: Recent associations of post 2003 non-phytoseiid ABAs.

<table>
<thead>
<tr>
<th>Family</th>
<th>ABA</th>
<th>Target-Pest</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acaridae</td>
<td>Sancassania</td>
<td>Nematodes</td>
<td>Karagoz et al. (2007)</td>
</tr>
<tr>
<td>Acarophenacidae</td>
<td>Acarophenax</td>
<td>Rhyzopertha</td>
<td>Gonçalves et al. (2003)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tribolium</td>
<td>Oliveira et al. (2003)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cryptoletes</td>
<td>Oliveira et al. (2003)</td>
</tr>
<tr>
<td>Anystidae</td>
<td>Anystis</td>
<td>Aculus</td>
<td>Cuthbertson et al. (2003a)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rhopalosiphum</td>
<td>Cuthbertson et al. (2003b)</td>
</tr>
<tr>
<td>Cheyletidae</td>
<td>Cheyletus</td>
<td>Tyrophagus</td>
<td>Palyvos et al. (2006)</td>
</tr>
<tr>
<td>Cunaxidae</td>
<td>Necunaxoides</td>
<td>Meloidogyne</td>
<td>Shoa and Kady (2009)</td>
</tr>
<tr>
<td>Erythraeidae</td>
<td>Balastium</td>
<td>Whiteflies</td>
<td>Fuentes et al. (2011)</td>
</tr>
<tr>
<td>Hemisarcoptidae</td>
<td>Hemisarcoptes</td>
<td>Chionaspis</td>
<td>Calmaur and Ozbek (2007)</td>
</tr>
<tr>
<td>Laelapidae</td>
<td>Androlaelaps</td>
<td>Dermanyssus</td>
<td>Lesna et al. (2012)</td>
</tr>
<tr>
<td></td>
<td>Stratiolaelaps</td>
<td>Fungus gnats</td>
<td>Cabrera et al. (2004)</td>
</tr>
<tr>
<td></td>
<td>Hypoaspis</td>
<td>Phoridae</td>
<td>Bingham (2004)</td>
</tr>
<tr>
<td></td>
<td>Hypoaspis</td>
<td>Frankiniella</td>
<td>Berndt et al. (2004)</td>
</tr>
<tr>
<td>Macrochelidae</td>
<td>Macrocheles</td>
<td>Thrips</td>
<td>Messelink &amp; van Holstein-Saj (2008)</td>
</tr>
<tr>
<td>Otopheidomenidae</td>
<td>Hemipteroseus</td>
<td>Pyrrhocoris</td>
<td>Lewandowski &amp; Szafranek (2005)</td>
</tr>
<tr>
<td>Pterogosomatidae</td>
<td>Pimelaphilus</td>
<td>Reduviidae</td>
<td>Martinez-Sanchez et al. (2007)</td>
</tr>
<tr>
<td>Pyeomotidae</td>
<td>Pyemotes</td>
<td>Hyphoborus</td>
<td>Akşit et al. (2007)</td>
</tr>
<tr>
<td>Stigmaeidae</td>
<td>Agistemus</td>
<td>Diaspididae</td>
<td>El-Sawi &amp; Momen (2006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Schizotetranychus</td>
<td>Horita et al. (2004)</td>
</tr>
<tr>
<td>Tarsonemidae</td>
<td>Tarsonemus</td>
<td>Schizotetranychus</td>
<td>Lin et al. (2002)</td>
</tr>
<tr>
<td>Trombidiidae</td>
<td>Trombidium</td>
<td>Hypera</td>
<td>Mohamed and Hogg (2004)</td>
</tr>
<tr>
<td>Uropodidae</td>
<td>Macrodinychus</td>
<td>Paratrechina</td>
<td>Gonzalez et al. (2004)</td>
</tr>
</tbody>
</table>

TABLE 2: Examples of phytoseiid species shown to have several strains.

<table>
<thead>
<tr>
<th>Species</th>
<th>Differing in</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amblyseius largoensis</td>
<td>Response to Raoiella</td>
<td>Carillo et al. (2012)</td>
</tr>
<tr>
<td>Amblyseius womersleyi</td>
<td>Olfactory responses</td>
<td>Maeda et al. (2001)</td>
</tr>
<tr>
<td>Euseius scutalis</td>
<td>Longevity, fecundity</td>
<td>Meyerdirk &amp; Coudriet (1986)</td>
</tr>
<tr>
<td>Galendromus occidentalis</td>
<td>Mating behavior</td>
<td>Hoy &amp; Cave (1985)</td>
</tr>
<tr>
<td>Neoseiulus californicus</td>
<td>Response to humidity</td>
<td>Walzer et al. (2007)</td>
</tr>
<tr>
<td>Phytoseiulus persimilis</td>
<td>Longevity, fecundity</td>
<td>Galazzi &amp; Nicoli (1996)</td>
</tr>
<tr>
<td>Phytoseiulus persimilis</td>
<td>Tolerance to aridity</td>
<td>Perring &amp; Lackey (1989)</td>
</tr>
<tr>
<td>Phytoseiulus longipes</td>
<td>Feeding preferences</td>
<td>Tixier et al. (2010)</td>
</tr>
<tr>
<td>Typhlodromus pyri</td>
<td>Temperature responses</td>
<td>Hardman &amp; Rogers (1991)</td>
</tr>
</tbody>
</table>
The systematics of other major ABA families is also being studied. The superfamily Raphignathoidea, containing the families Camerobiidae, Eupalopsellididae and Stigmaeidae, of biocontrol interest, were partially revised by Fan and Zhang (2005). Other recent contributions include van der Schyff et al. (2005, Bdellidae); Hartini et al. (2009, Macrochelidae); Lindquist and Moraza, (2010, Platysociidae); Joharchi et al. (2011, Laelapidae); Reis et al. (2011, Eriophyidae) and Skvarla et al. (2014, Cunaxidae). Authors describing new taxa in various families often note that these mites may have potential as BC agents (e.g. de Moraes 2010; Rector and Petanović 2012).

**ADDITIONS TO THE ROSTER OF ABAS AND THEIR PREY/HOSTS**

Gerson et al. (2003) listed 34 acarine families that include members known, or postulated, to reduce pest (including, as above, weeds and pathogens) numbers and/or their damage. Representatives of one more family (Uroactiniinae) have since been added. Predatory mites that potentially or actually affect pests which have recently invaded new regions (Cox et al. 2006; Furtado et al. 2007), or pests that have not hitherto been known to be affected by ABAs, are likewise noted.

Adults of the red palm weevil, Rhynchophorus ferrugineus (Olivier) (Coleoptera: Curculionidae), a pest of palms, were heavily (57-95 %) attacked by Centrouropoda almerodai Wisniewski et al. (Uroactiniinae), which reduced the lifespan of infested individuals by one-third (Mazza (Uroactiniidae); Hartini et al. (2009, Macrochelidae); Lindquist and Moraza, (2010, Blattisociidae); Joharchi et al. (2011, Laelapidae); Reis et al. (2011, Eriophyidae) and Skvarla et al. (2014, Cunaxidae). Authors describing new taxa in various families often note that these mites may have potential as BC agents (e.g. de Moraes 2010; Rector and Petanović 2012).

Gerson et al. (2003) listed 34 acarine families that include members known, or postulated, to reduce pest (including, as above, weeds and pathogens) numbers and/or their damage. Representatives of one more family (Uroactiniinae) have since been added. Predatory mites that potentially or actually affect pests which have recently invaded new regions (Cox et al. 2006; Furtado et al. 2007), or pests that have not hitherto been known to be affected by ABAs, are likewise noted.

Adults of the red palm weevil, Rhynchophorus ferrugineus (Olivier) (Coleoptera: Curculionidae), a pest of palms, were heavily (57-95 %) attacked by Centrouropoda almerodai Wisniewski et al. (Uroactiniinae), which reduced the lifespan of infested individuals by one-third (Mazza et al. 2011). Macrodinychus sellnicki (Hirschmann and Zingiebl-Nicol) (Uropodidae) is an ectoparasitoid of the crazy ant, Paratrechina fulva (Mayr), a pest of sugar cane in Colombia. The mite feeds on the ant’s pupae, which subsequently die. Despite high rates of attack (up to 93 %), the mass production of this ABA was not feasible, and Gonzalez et al. (2004) recommended inoculative releases of field-collected, highly parasitized hosts into ant colonies. Three phytoseiids, namely Neoseiulus cucumeris (Oudemans), N. barkeri (Hughes) and Amblyseius swirsii Athias-Henriot, were assayed against the Asian citrus psyllid, Diaphorina citri Kuwayama, the vector of the bacterium causing huanglongbing (HLB), the devastating citrus greening disease. All three predators had a significant negative impact on the pest (Juan Belasco et al. 2012; Fang et al. 2013). Pappas et al. (2013) assayed for instance Phytoseius finitimus Ribaga against spider mites and whiteflies. Ali et al. (2012) indicated that Dermanyssus gallinae (De Geer) (Dermanyssidae), a major pest of poultry world-wide, may be partially controlled by Hypoaspis miles (Berlese) [probably Stratiolaelaps scimitus (Womersley)]. The macrochelid Macrocheles robustulus (Berlese) was newly found to be an efficient predator of thrips (Messelink and van Holstein-Saj 2008). Pimeliaphilus plumifer (Newell and Ryckman) (Prostigmata: Pterygosomatidae) parasitizes Meccus pallidipennis (Stål) (Hemiptera: Reduviidae), a vector of Chagas disease in Mexico. Mite attack increased the mortality and reduced the molting rates in bug nymphs, as well as the longevity and fecundity of the surviving females (Martinez-Sanchez et al. 2007). The authors advocated the use of Pimeliaphilus plumifer as a control agent of this and other vector species. Acarophenax lacunatus (Cross and Krantz) (Acarophenacidae) fed on the eggs of several beetle pests of stored food. Its highest parasitization rates were on the beetles Rhyzopertha domini ca (Fabricius) (Bostrichidae) and Tribolium castaneum (Herbst) (Tenebrionidae), resulting in reduced pest numbers and in increased wheat weight (Oliveira et al. 2003). Numbers of the cigarette beetle, Lasioderma serricorne (Fabricius) (Anobiidae), a major pest of tobacco, were reduced by about 20 % due to feeding by Tyrophagus putrescentiae (Schrank) (Acarophenacidae) (Bosch). According to Caneveri et al. (2012) this mite killed 54-78 % of the pest’s larvae and its use in beetle management programs was advocated. Riccardoella limacum (Schrank) (Prostigmata: Erynetidae) lives in the lung cavity of the land snail Arianta arbustorum Linnaeus (Mollusca: Helicidae), of quarantine importance in the United States (Cowie et al. 2009). The mite infested 45-70 % of several snail populations, seriously reducing their survival (Schupbach and Baur 2008).

Routine examinations of insect pests often reveal...
many associated ABAs (Elkawas 2011), but their effect on the prey/hosts and on the extent of damage remains to be determined.

**HOW ABAS AFFECT PESTS (INCLUDING WEEDS AND FUNGI) AND REDUCE THEIR DAMAGES**

ABAs reduce pest numbers and/or their damage by various modes; some examples are listed in Table 3. Predation is the commonest, phytoseiids being supreme in this respect. Parasitism (feeding on the host without killing it, but reducing viability and fecundity) is often observed with water mites of the family Arrenuridae (Smith and McIver 1984). Other parasites, feeding on their hosts and killing them, are *Pyemotes* spp. (Pyemotidae) and *Hemisarcoptes* spp. (Hemisarcoptidae) (Aksit et al. 2007; Calmaur and Ozbek 2007, respectively). Parasitic castration of the grasshopper, *Hieroglyphus nigrorepletus* Bolivia (Acrididae) is due to the feeding of *Eutrombidium trigonum* (Hermann) (Badruddin et al. 2003) (Trombididae). Members of over 30 mite families (e.g. Acaridae, Aycidae, Galumnidae, Laelapidae and others) feed on nematodes, greatly reducing their numbers (Gerson, in press). The tydeid *Orthotydeus lambi* (Baker) grazed on the mycelia of grape powdery mildew and reduced its spread on the foliage and fruit of nine grape cultivars; extent of disease suppression depended on the specific grape genotypes, their susceptibility to the mildew and on mite numbers (English-Loeb et al. 2007).

Indirect damage to a pest can be due to several species of *Tarsonemus* (Tarsonemidae) associ-

**Table 3: Examples of the mechanisms by which ABAs affect pest organisms.**

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Reference</th>
<th>ABA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predation</td>
<td>Carrillo et al. (2012)</td>
<td><em>Amblyseius</em></td>
</tr>
<tr>
<td></td>
<td>Shoala and El Kady (2009)</td>
<td><em>Neocunaxoides</em></td>
</tr>
<tr>
<td>Parasitism</td>
<td>Martinez-Sanchez et al. (2007)</td>
<td><em>Pimeliaphilus</em></td>
</tr>
<tr>
<td>Parasitoidism</td>
<td>Gonzalez et al. (2004)</td>
<td><em>Macrodinychus</em></td>
</tr>
<tr>
<td>Fecundity reduction</td>
<td>Smith and McIver (1984)</td>
<td><em>Arrenurus</em></td>
</tr>
<tr>
<td>Parasitic castration</td>
<td>Badruddin et al. (2003)</td>
<td><em>Eutrombidium</em></td>
</tr>
<tr>
<td>Competition</td>
<td>Hougen-Eitzman and Karban (1995)</td>
<td><em>Eotetranychus</em></td>
</tr>
<tr>
<td>Disease transmission to pests</td>
<td>Seeman (2008)</td>
<td><em>Chrysomelobia</em></td>
</tr>
<tr>
<td>Reduction of fungal growth</td>
<td>Enami and Nakamura (1996)</td>
<td><em>Scheloribates</em></td>
</tr>
<tr>
<td>Reduction of weed growth</td>
<td>Marlin et al. (2013a)</td>
<td><em>Orthogalumna</em></td>
</tr>
</tbody>
</table>
ated with the southern pine beetle, *Dendroctonus frontalis* Zimmerman (Coleoptera: Curculionidae), a destructive pest of pine trees in North America. The mites carry ascospores of the bluestain fungus *Ophiostoma minus* (Hedgcock), which outcompete fungi carried by *D. frontalis*, critical for its nutrition. The pest larvae seldom survived in the presence of *O. minus* (compared to 83% survival elsewhere). By disrupting beetle mutualism with *O. minus* the mites indirectly reduced pest numbers (Lombardero et al. 2003). The water hyacinth, *Eichhornia crassipes* (Mart.) Solms (Pontederiaceae), is a weed that forms dense mats in waterways in many parts of the world. *Orthogalumna terebrantis* (Wallwork (Galumnidae) feeds on the weed, reducing its physiological activity (Marlin et al. 2013a).

ABAs can damage pests by transmitting diseases. The Pales weevil, *Hylobius pales* (Herbst) (Curculionidae), a forestry pest, carried a phoretic *Macrocheles* sp. (Macrochelidae). The mites, contaminated with the entomopathogenic fungus *Metarhizium anisopliae* (Metchnikoff) Sorokin (Hypocreales: Clavicipitaceae) transmitted it to the weevils, of which ca 80% became infected (as compared to 7% in the mite-free weevil control group) (Schabel 1982).

**INTRA-ABA INTERACTIONS**

**Intraguild predation**

Intraguild predation (IGP) can take place when two natural enemies share a host (or prey), and at least one also feeds on the other (Rosenheim et al. 1995). IGP is common amongst ABAs but their interactions can also be competitive without predation, or even increase the extent of control. These interactions may promote or hinder pest control. An ABA might win the contest, but if the less efficient predator becomes dominant, the extent of pest control would then be reduced. The outcome of such contests depends on the competing species, on their nutrient requirements (usually pollen for phytoseiids), on the season (Hatherly et al. 2005) and whether the competitors are (among phytoseiids) the specific Type 1 predators or more of the generalist Types (e.g. Palevsky et al. 2013). Contestants’ size, the plant and any applied pesticides are also important, leading to very different outcomes. The phytoseids *N. cucumeris* and *N. barkeri* co-occur in European glasshouses, feeding on *Thrips tabaci* Lindeman. The former is the better predator, but on parthenocarpic cucumbers (which do not produce pollen) it was displaced by *N. barkeri*. This was attributed to the latter’s greater mobility, to lesser dependence on pollen and/or to more prey consumed (BrØdsgaard and Stengaard Hansen 1992). On sweet pepper, however, *N. cucumeris* attained higher numbers than *N. barkeri*, even when the latter was released first or in larger numbers (Rakers 1988). When *A. swirskii* and *N. cucumeris* were applied against the western flower thrips (*Frankliniella occidentalis* Pergande (Thripidae), they preferred each other’s juveniles over the pest (Buitenhuis et al. 2010), resulting in less pest control. Seelmann et al. (2007) hypothesized that leaf pubescence of apple varieties mediates IGP between the phytoseiids *Kampimodromus aberrans* (Oudemans) (which prefers pubescent leaves) and *Euseius finlandicus* (Oudemans) (which lives mostly on glabrous leaves) and thereby determines their proportional abundance in orchards. The outcome of IGP amongst *N. cucumeris*, the laelapid *S. scimitus* and the beetle *Atheta coriaria* (Kraatz) (Staphylinidae), as it affected thrips control in a greenhouse, was explored by Pochubay and Grieshop (2012). When all three predators co-occurred, numbers of the latter two were reduced whereas prey thrips populations grew five-fold larger than with *N. cucumeris* alone, advocating the use of only the latter for thrips control.

The level and severity of IGP also bears on the establishment, success and survival of exotic natural enemies. Palevsky et al. (2013) analysed the history of several exotic phytoseiids introduced into different parts of the world to control mite pests. In most cases the exotic predators, as they became established, enhanced pest control without adversely affecting the local predators. However, the latter (especially species of the pollen-feeding *Euseius*) often reduced the exotic species, either by surviving after numbers of the common prey had been reduced, and/or by feeding on the eggs and juve-
niles of the exotics (Palevsky et al. 1999). IGP may be avoided if the contestants inhabit different plant strata (Zannou et al. 2007), by placing their eggs in domatia (see below) or by the availability of other nutrients (e.g. pollen, Onzo et al. 2005). Plant-protection chemicals also affect the outcome. Sato et al. (2001) monitored phytoseiid and stigmaeid populations in Brazilian citrus groves after pesticide applications. The increases in stigmaeid numbers were postulated by the authors to be due to the greater sensitivity of the phytoseiids to the chemicals.

Interactions between ABAs and arthropathogenic fungi form another facet of IGP, which often detracts from ABA efficacy. When the phytoseiid Phytoseiulus persimilis Athias-Henriot was offered Tetranychus urticae Koch (Prostigmata: Tetranychidae) (the two-spotted spider mite, TSSM) infected with the fungus Beauveria bassiana (Balsamo) Vuillemin (Hypocreales: Clavicipitaceae), the predator’s fecundity declined (Seiedy et al. 2012). When the same predator was assayed, along with the fungus Neozygites floridana (Fisher) (Entomophthorales: Neozygitaceae) to control Tetranychus evansi Baker and Pritchard (Prostigmata: Tetranychidae), a pest of Solanaceous crops, the predator produced fewer eggs. Wekesa et al. (2007) attributed this to increased grooming by P. persimilis in order to remove conidia that had become attached to its body. In none of these cases did the fungi infect the predators. These data suggest that applying ABAs with arthropathogenic fungi may not improve pest control.

ABAs that increase the extent of control

At times ABAs alone cannot reduce pest numbers to below their economic injury levels and other natural enemies help to attain that goal. Control of the stored food beetle pest Oryzaephilus surinamensis Linnaeus (Silvanidae), by Cheyletus eruditus (Schrank) (Cheyletidae) was improved when the hymenopterous parasitoid Cephalonomia tarsalis (Ashmead) (Bethylidae) was introduced into the food bin (Ždarkova et al. 2003). Another group of natural enemies are nematodes. The release of Gavolaelaps aculeifer (Canestrini) (Laelapidae) (then known as Hypoaspis aculeifer) along with nematodes, significantly reduced the numbers of the WFT infesting green beans (Premachandra et al. 2003), as well as sciarids and phorids (Diptera), pests of mushrooms in compost and casing substrates (Jess and Bingham 2004). The predatory cecidomyiid Therdiplosis persicae (Kieffer) (Diptera) "supported" the control of T. urticae by P. persimilis on tomatoes in a greenhouse (Fiedler 2005), and the generalist ant Pseudomyrmex punctatus Mayr "enhanced" the control of the spider mite Tetranychus kanzawai Kishida by Neoseiulus womenzleyni Schicha (Otsuki and Yano 2014). The greatest damage to the leaf surface area of water hyacinth occurred when the Hemipteran Ecreritatorus catarinensis (Carvalho) (Miridae) was used along with O. terebrantis (Marlin et al. 2013b).

Such results are generally consistent with the opinions of Stiling and Cornelissen (2005), who calculated that the addition of two or more biocontrol agents, especially if generalists, increased pest mortality by 13 %, decreasing pest abundance by 27.2 %, as compared to single releases or when BC agents were specialists. This may be explained by the ability of generalists to survive on the crop when the numbers of the target-pest are much reduced, and will thus be in place if the pest resurges (e.g. Palevsky et al. 2013).

The impact of host plants on ABAs

Plants are the habitat where herbivores live, feed and encounter their natural enemies, and are thus a major, interactive component of BC practices (Cortesero et al. 2000). Plants provide suitable or unsuitable arenas for predators (e.g. hairs, domatia), supplementary or entire diets (e.g. the leaf itself, pollen, various exudates) and host/ prey finding cues (e.g. volatiles), thus mediating pest-ABA interactions and their intensity. More predatory mites of the genera Amblyseius and Hypoaspis were found in soil under Bromus sterilis Linnaeus than underneath Taraxacum officinale (Linnaeus) (Wisuwa et al. 2012). Secondary plants, different plants or a secondary crop, grown along with the primary crop, are known to affect pests and their natural enemies (Parolin et al. 2012). An example is the weed
Ageratum conyzoides Linnaeus, intercropped in a citrus orchard, which continuously released volatiles that maintained populations of Scapulaseius newsami (Evans) which reduced those of the spider mite pest Panonychus citri (McGregor) (Kong et al. 2005).

**Plant architecture**

Pratt et al. (2002) compared the efficacy of Neoseiulus fallacis (Garman) against spider mites on various ornamentals, and found that plant architecture and foliar density were the major factors in predicting successful BC. This predator was most effective on shrubs and herbaceous perennials, less effective on conifers and shade trees. The foraging of *P. persimilis* on cucumber was affected by variations in plant structures, such as surface area, vestiture and the numbers, kinds and proportions of plant parts (Gontijo et al. 2012).

Many ABAs, especially phytoseiids, occur on wild and cultivated plants that grow near or within crops, and may serve as sources for predators (i.e. Mailloux et al. 2010). This idea was developed by using banker plants, intended to provide and sustain a reproducing and releasing system of natural enemies within a crop, providing long-term pest suppression (Huang et al. 2011; Parolin et al. 2013). An advantage of this system over augmentative BC is the continuous release of ABAs without their repeated, costly re-colonizations (Frank 2010). An early example was placing potted castor bean plants bearing the phytoseiid Iphiseius degenerans (Berlese) among pepper plants. After feeding on the castor bean pollen, the predator moved onto the peppers to control thrips there (Ramakers and Voets 1996). The leaf surfaces of crops affect foraging ABAs, a topic recently reviewed by Schmidt (2014), will only be briefly discussed. The stigmaeid Agistemus exsertus Gonzalez, a predator of pest mites in Egypt, developed best on smooth, glabrous foliage, whereas rough, pubescent leaves were unsuitable for oviposition (Saber and Rasmy 2010). Likewise, more larvae of the onion thrips, *T. tabaci*, were attacked by *N. cucumeris* on the almost glabrous leaves of sweet pepper than on the more pilose foliage of cucumber and eggplant (Madadi et al. 2007). As noted, grape leaf pubescence may affect IGP outcomes. Similarly, Duso et al. (2003) found that *Tychlodroms pyri* Scheuten (Phytoseiidae) was more abundant on an apple variety with highly pubescent leaves than on foliage with few hairs. Kreiter et al. (2002) and Tixier et al. (2003) emphasized the importance of complex phylloplanes for *K. aberrans* on various plants, probably because dense trichome “forests” caught more pollen, providing nutrients for this ABA. The glandular trichoms on tomato stems and leaves bear sticky globules that may entrap predators; Drukker et al. (1997) have selected strain of *P. persimilis* that has adapted to performing on tomatoes.

Domatia are minute invaginations, pits or pouches that may be hidden by tufts of hairs often located on the undersides of leaves, can house various ABAs and fungivorous mites. These “resident” ABAs (mostly Phytoseiidae and Tydeidae) reduce IGP between ABAs. Leaves of Cinnamomum camphora (Linnaeus) J. Presl. bear four types of domatia, which enable the coexistence of antagonistic mites, including Eriophyidae and Phytoseiidae (Nishida et al. 2005). The phytoseiids Amblyseius herbicolus Chant and *Iphiseiodes zuluagai* Denmark and Muma co-occur on coffee and feed on each-other’s larvae. Domatia on detached coffee leaves were either closed with glue or left open, and larvae and adults of both predators were released. Survival of larvae of both species was significantly higher (e.g. less IGP) on leaves with open domatia than on leaves with closed domatia (Ferreira et al. 2011). In addition, *I. zuluagai* preferred to place its eggs inside domatia. Matos et al. (2004) for instance advocated selecting coffee plants with domatia that would harbor predatory mites, in-built bodyguards, as protection against pest mites.

**Phylloplane (hairy leaves and shelters, including domatia)**

The leaf surfaces of crops affect foraging ABAs, a topic recently reviewed by Schmidt (2014), will only be briefly discussed. The stigmaeid Agistemus exsertus Gonzalez, a predator of pest mites in Egypt, developed best on smooth, glabrous foliage, whereas rough, pubescent leaves were unsuitable for oviposition (Saber and Rasmy 2010). Likewise, more larvae of the onion thrips, *T. tabaci*, were attacked by *N. cucumeris* on the almost glabrous leaves of sweet pepper than on the more pilose foliage of cucumber and eggplant (Madadi et al. 2007). As noted, grape leaf pubescence may affect IGP outcomes. Similarly, Duso et al. (2003) found that *Tychlodroms pyri* Scheuten (Phytoseiidae) was more abundant on an apple variety with highly pubescent leaves than on foliage with few hairs. Kreiter et al. (2002) and Tixier et al. (2003) emphasized the importance of complex phylloplanes for *K. aberrans* on various plants, probably because dense trichome “forests” caught more pollen, providing nutrients for this ABA. The glandular trichoms on tomato stems and leaves bear sticky globules that may entrap predators; Drukker et al. (1997) have selected strain of *P. persimilis* that has adapted to performing on tomatoes.

Domatia are minute invaginations, pits or pouches that may be hidden by tufts of hairs often located on the undersides of leaves, can house various ABAs and fungivorous mites. These “resident” ABAs (mostly Phytoseiidae and Tydeidae) reduce IGP between ABAs. Leaves of Cinnamomum camphora (Linnaeus) J. Presl. bear four types of domatia, which enable the coexistence of antagonistic mites, including Eriophyidae and Phytoseiidae (Nishida et al. 2005). The phytoseiids Amblyseius herbicolus Chant and *Iphiseiodes zuluagai* Denmark and Muma co-occur on coffee and feed on each-other’s larvae. Domatia on detached coffee leaves were either closed with glue or left open, and larvae and adults of both predators were released. Survival of larvae of both species was significantly higher (e.g. less IGP) on leaves with open domatia than on leaves with closed domatia (Ferreira et al. 2011). In addition, *I. zuluagai* preferred to place its eggs inside domatia. Matos et al. (2004) for instance advocated selecting coffee plants with domatia that would harbor predatory mites, in-built bodyguards, as protection against pest mites.

**Pollen**

Pollen may be the main diet of some phytoseiids or provide subsistence nutrients, maintaining and allowing predator development when prey is scarce. The availability of pollen can, as noted, affect the outcome of IGP contests between phytoseiids. Not all phytoseiids feed on pollen of the same plant
(Gerson et al. 2003); pollen of some plants may be rejected by one species while devoured by another (Kolokytha et al. 2011). Pollens of Carpobrotus edulis Linnaeus (Aizoaceae) and of Scrophularia peregrina Linnaeus enabled 84 % of the larvae of Neoseiulus californicus (McGregor) to reach adulthood, whereas only 28 % reached adulthood when fed mint, Mentha piperita Linnaeus, pollen (Ragusa et al. 2009). The beneficial effects of various pollens, whether from nearby hedgerows or from Rhodes grass, to phytoseiid abundance and pest control, were for instance reported by Duso et al. (2004) and by Maoz et al. (2011). The availability of pollen may however have unexpected results. Aguilar-Fenollosa et al. (2011) studied the effect of pollen of plants that grow in Spanish citrus groves on TSSM BC. Other ABAs, like Butyrospermum parkii (Jacq.) Schwant, provided their use has no negative non-target effects (Lövei et al. 2009); little has been written in regard to ABAs. The effect of pollen from GM maize (expressing the BTcry1Ab toxin) on ABAs was explored by Obrist et al. (2006). The development of N. cucumeris females offered pollen from transformed (Bt+) maize was slightly prolonged and their fecundity was reduced, in comparison with females offered untransformed (Bt-) pollen. This was attributed to the possible reduction in the nutritional quality of the Bt+ pollen rather than to any direct toxin direct. Zemek (2007) reached similar conclusions in regard to N. cucumeris, P. persimilis and T. pyri feeding on T. urticae infesting GM maize, although large amounts of the toxin accumulate in the preys’ bodies (Torres and Ruberson 2008). No detrimental effects of various BTCry toxins, offered at field concentrations, on Euseius concordis (Chant) (toxins in drinking water) and on N. californicus (preying on T. urticae feeding on Bt+ cotton) were found by de Castro et al. (2013). A concentration of 0.018 mg/ml however reduced the reproduction of the former. Significantly fewer TSSM were consumed by P. persimilis on Bt+ eggplants than on Bt- plants, disrupting pest control (Rovenská et al. 2006).

Volatile

Many pest- and spider mite-damaged plants release volatiles that attract natural enemies (Kessler and Baldwin 2001), including phytoseiids. Although diverse volatiles attract predators (Shimoda et al. 2005), methyl salicylate (MeSA) appears to be the commonest attractant especially for P. persimilis attracted by plants attacked by T. urticae. Several other phytoseiids, including N. californicus (Shimoda et al. 2005), N. vooversleyi (Ishiwari et al. 2007), N. cucumeris (Tatemoto and Shimoda 2008), N. fallacis (Gardiner et al. 2005); S. neesami (Kong et al. 2005), Typhlodromalus manihoti (de Moraes) and T. Berliner (Bt) endotoxins has become common (Harrow et al. 2005). The potential of genetically modified (GM) plants as components of integrated pest management (IPM) was discussed by Kos et al. (2009), who discussed that GM crops which express predator-attracting volatiles could enhance BC, provided their use has no negative non-target effects (Lövei et al. 2009); little has been written in regard to ABAs. The effect of pollen from GM maize (expressing the BTcry1Ab toxin) on ABAs was explored by Obrist et al. (2006). The development of N. cucumeris females offered pollen from transformed (Bt+) maize was slightly prolonged and their fecundity was reduced, in comparison with females offered untransformed (Bt-) pollen. This was attributed to the possible reduction in the nutritional quality of the Bt+ pollen rather than to any direct toxin direct. Zemek (2007) reached similar conclusions in regard to N. cucumeris, P. persimilis and T. pyri feeding on T. urticae infesting GM maize, although large amounts of the toxin accumulate in the preys’ bodies (Torres and Ruberson 2008). No detrimental effects of various BTCry toxins, offered at field concentrations, on Euseius concordis (Chant) (toxins in drinking water) and on N. californicus (preying on T. urticae feeding on Bt+ cotton) were found by de Castro et al. (2013). A concentration of 0.018 mg/ml however reduced the reproduction of the former. Significantly fewer TSSM were consumed by P. persimilis on Bt+ eggplants than on Bt- plants, disrupting pest control (Rovenská et al. 2006).

GMO (genetically modified organisms)

Pest control via transgenic (genetically modified) crops expressing the various Bacillus thuringiensis

aripe De Leon (Gnanvossou et al. 2003) showed such attraction. The effect of A. conyzoides volatiles on populations of S. newssami was noted above.

Finally, in the laboratory the feeding of Acreia tulipae Keifer (Eriophyidae) on onion bulbs attracted N. cucumeris. However, as the bulbs are belowground, the results show only the potential for odour-mediated interactions in the soil; their significance remains to be demonstrated (Aratchige et al. 2004). The potential of attracting predators with plant volatiles in order to promote BC was discussed by Kaplan (2012). The dangers of non-target effects, like attracting enemies of the BC organisms (the "4th level consumers"), which could reduce biological control, and cause changes in BC communities, were among the risks noted.

**ABAs in the soil**

ABA activities in the soil were reported to limit the numbers of molting thrips, corn root worms (Diabrotica virgifera LeConte, Coleoptera: Chrysomelidae) and of nematodes, and in reducing the inoculum of plant-pathogenic fungi (Gerson et al. 2003). The great abundance of predatory mites in soils (Lundgren et al. 2009), including Phytoseiidae (Mineiro et al. 2012), suggests that they are an under-utilized BC resource.

Berndt et al. (2004) estimated the predatory capacity of S. scimitus and G. aculeifer (known in commerce as Hypoaspis), which feed on the soil-inhabiting molting stages of WFT. The latter, which was the better predator, had significantly more eggs, reproduced faster and raised larger populations. The authors concluded that G. aculeifer could control thrips populations with a release of 520 individuals/square meter. Their efficacy is due to the fact that they inhabit the same soil strata; the presence of other prey (e.g., nematodes, Collembola) may however detract from their controlling effect (Wiethoff et al. 2004). Another soil-borne predator, Lasiosius finetorum Berlese (Ascidae), was compared by Enkegaard and Brødsgaard (2000) with S. scimitus. The former developed faster and had more progeny on thrips prey.

Large populations of G. aculeifer were associated with fewer numbers of the pest thrips Pezothrips kellyanus (Bagnall), which molts in the soil, and with less damage to citrus fruit. Adding composting manure to the soil was advocated by Navarro-Camposa et al. (2012) as a means of increasing mite numbers, thereby promoting the pest's control.

Species of Gaeolaelaps and of Stratiolaelaps feed on eggs and larvae of corn rootworm in the soil. Prischmann et al. (2011a) concluded that although they do not seriously reduce pest numbers, they may regulate immature rootworm populations. Qualitative and quantitative methods for monitoring ABA feeding in the soil are discussed below.

Plants may affect ABAs through their symbiotic associations with arbuscular mycorrhizal (AM) fungi and/or rhizobacteria. The growth rate of P. persimilis was enhanced when feeding on TSSM infesting these plants (Hoffmann et al. 2011). Further, mycorrhizal bean plants infested by TSSM attracted more predators than non-mycorrhizal beans (Schausberger et al. 2012). These results were obtained with plants grown in pots; their validity in the field remains to be determined. More P. persimilis occurred on cucumbers treated with plant growth promoting rhizobacteria than on untreated plants, and more prey (TSSM) were located thereon by the predator (Tomczyk and Burda 2005).

**WEEDS, NEMATODES AND ABAS**

Gorse (Ulex europaeus Linnaeus) is an invasive spiny shrub that is an important weed in Australia, Hawaii, New Zealand and North America (Rees and Hill 2001). The early success of Tetranychus lintearius Dufour (Tetranychidae) in its control is currently being curtailed by phytoseiid predators (Davies et al. 2009).

The great specificity of eriophyids to their host plants has made them ideal agents of weed control (reviewed by Smith et al. 2010). The assayed eriophyids were listed and the few that were released and had become established were noted. Although the fitness of the target plants was reduced, it was not clear to what extent did the mites reduce weed populations. Such partial results were attributed to
natural enemies (noted above), resistant plant genotypes, and to adverse abiotic conditions. In addition, some eriophyids have co-evolved with their host weeds and may thus be unsuitable for controlling them (because of low harmfulness).

Several eriophyids vector viral plant diseases that could be used for weed control. Weed pathogens can also be spread by other ABAs. The erythraeid _Balaustium_ sp. (Prostigmata) carried spores of several plant pathogenic fungi without being infected (Yoder et al. 2009).

Members of about 30 families contain nematophagous mites, consisting of members of the Mesostigmata, Astigmata (Astigmata), Oribatida (Cryptostigmata), Endostigmata and Prostigmata (Gerson, in press). Such species abound in soils; Beaulieu and Walter (2007) collected almost 70 Mesostigmata from the soil and litter of Australian forests, most of which were generalist predators that fed on nematodes. They differ in their feeding habits: some swallow the entire nematode ("engulfers"), whereas others puncture and mangle their prey, ingesting the body fluids. They may roughly be consigned to three functional groups (Walter et al. 1988), namely general feeders, fungivores and detritivores, and specialized predators of nematodes. No member of the latter group is known to reduce populations of pest nematodes.

Soil type strongly affects mite predation on nematodes, being strongest in sandy, light to medium soils (El-Banhawy et al. 2006). Evidence for mite control of nematodes in pots was provided, among others, by Shoala and El Kady (2009), who showed that 60 females of the cunaxid _Neocunaxoides andrei_ (Baker and Hoffmann) significantly reduced the numbers of _Meloidogyne javanica_ (Treub) galls on tomato roots. Other aspects of mite-nematode interactions were discussed by Gerson (in press).

A drawback for using nematophagous mites would be their preying on entomopathogenic nematodes (EPN), applied against other pests. A recent example is _Sancassania polyphyllae_ (Zachvatkin) (Acaridae), which attacks the infective nematode juveniles (IJ) of the EPN _Steinernema glaseri_ (Steiner) that emerge from cadavers of their beetle host (Cakmak et al. 2013).

**DISEASES OF ABAS**

The diseases of phytoseiids were recently summarized by Bjornson (2008), Hoy and Jeyaprakash (2008) and by Schütte and Dicke (2008); data on other ABAs were unavailable. Microorganisms found on and in various Phytoseiidae were listed by Schütte and Dicke (2008), but only a few caused any damage, mostly when the predators are under stress, as in mass-rearing facilities. The disease factors include the bacterium _Acaricomus phytoseiuli_ Schütte et al. and several microsporidia. The bacterium, apparently restricted to _P. persimilis_, is transmitted via feces and debris, causing reduced fitness. The phytoseiid _Galendromus occidentalis_ (Nesbitt) (formerly in _Metaseiulus_) infected by _Cardinium_, a bacterium from the _Bacteroidetes_ group, has a shorter life, fewer progeny and a male-biased sex ratio (Wu and Hoy 2012). The microsporidium _Oligosporidium occidentalis_ Becnel et al. shortens the life of _G. occidentalis_, reduces its fecundity and causes a male-biased sex ratio (Hoy and Jeyaprakash 2008).

Only few viruses were detected in the Phytoseiidae and their negative effects are unknown (Schütte and Dicke 2008). There are also a few reports of diseases affecting ABAs in the field, e.g. an infection of _Euseius citrifolius_ Denmark and Muma by the fungus _Neozygites_ sp. in Brazil (Furtado et al. 1996). The presence of potential disease factors on and in ABAs in the field may become a problem when they are brought into the laboratory to be mass-reared; requiring screening and sanitation procedures.

**THE EFFECT OF PESTICIDES ON ABAS**

ABAs are often affected by pesticides applied against co-occurring pests, and information about their effects on ABAs is thus required. The relevant literature is very large and only a sample will be presented. Bernard et al. (2004) suggested standards for the ecotoxicological testing of various pesticides and their acute and sublethal effects on phytoseiids. Most data concern _P. persimilis_, which appears to be tolerant to many acaricides and insecticides (Ahn et al. 2004; Lash et al. 2007; Lee et al. 2008). According
to Bostanian et al. (2009), thiacloprid, spinosad and methoxyfenoxide were harmless to the adults of *P. persimilis* and had no effect on fecundity, but showed some repellence at 24 h intervals for 72 h. Argolo et al. (2014) compared the relative toxicity several pesticides on the phytoseiids *Euseius stipulatus* (Athias-Henriot), *N. californicus* and *P. persimilis*. The most tolerant was *E. stipulatus*, followed by *N. californicus* and by *P. persimilis*, indicating that the latter should be used as an indicator species of pesticide effects on predacious mites occurring in Spanish citrus orchards. *Stratiolaelaps scimitus* was very susceptible to dicofol and chlorpyrifos but the insect growth regulator (IGR) pyriproxyfen and some fungicides were almost harmless (Cabrera et al. 2004). The plant-derived rotenone and pyrethrins were very lethal to *P. persimilis* (Duso et al. 2008). *Acarophenax lacunatus*, although tolerant to various pyrethroids, still parasitized eggs of *R. dominica* (Gonçalves et al. 2004). Diatomaceous earth formulations have been assayed against various food pests. Athanassiou and Palyvos (2006) reported that *Blattisocius keegani* Fox (Mesostigmata, Ascidae) and *Cheyletus malaccensis* (Oudemans) were very susceptible to these compounds. As to fungicides, Auger et al. (2005) found that *K. aberrans* and *T. pyri* showed variable resistance to the fungicide mancozeb.

**NEW TECHNIQUES IN ABA APPLICATION**

Rearing, distributing, long-term maintenance and overwintering of ABAs

Methods for mass-rearing ABAs (those that are not protected by patents) and for quality control were noted by Gerson et al. (2003). More recently Nguyen et al. (2014) developed an artificial diet for *A. swirskii*, and Freire and de Moraes (2007) described a new method for mass producing *S. scimitus*. BC personnel have used various methods for the distribution of ABAs in greenhouses. A mechanical dispenser to distribute *P. persimilis* in a rose greenhouse was used by Casey and Parrella (2005), reducing TSSM infestations by about 50 %. Opit et al. (2005) used mechanical blowers to disperse phytoseiids in a greenhouse, the blowers providing better coverage than the manual method. Shaw and Wallis (2007) applied *P. persimilis* against TSSM infesting hop by a motorized leaf blower, a method four times faster than hand distributing, and Adar et al. (2014) provided pollen on-twine for phytoseiids in greenhouses.

Ghazy and Amano (2014) reported that mated females of the Japanese strain of *N. californicus*, maintained at 100 % RH and 5 °C, survived for several weeks without affecting the quality of their progeny (egg hatchability, survival and sex ratio), data that could promote ABA survival during unexpected changes in temperatures and for storing before releasing. Young females of *P. persimilis* tolerated prolonged (18 days) exposure to either 5 or 10 °C and starvation without compromising their quality (Luczynski et al. 2008). Such data promotes the long-term storage of these (and possibly other) phytoseiids. Kawashima and Jung (2010) placed artificial shelters on the ground to monitor the winter survival of several phytoseiids in an apple orchard in Japan. This idea was developed by Szabo and Penezes (2013) who transferred ground litter from orchards containing large numbers of the overwintering phytoseiid *Amblyseius andersoni* (Chant) to young orchards, thereby significantly increasing their numbers in the control plots.
Molecular methods

Cuthbertson et al. (2003b) and Prischmann-Voldseth et al. (2011b) used PCR (polymerase chain reaction) to determine the extent of feeding by Anystidae and Laelapidae on aphids, and on corn rootworms and nematodes, respectively. Estimates of the consumption of *D. virgifera* immatures by various predators were obtained by Lundgren et al. (2009), who analyzed the predators’ gut contents by using *D. virgifera*-specific DNA sequences with the quantitative polymerase chain reaction (qPCR). The data were used to generate taxon-specific prey consumption indices for the major predator taxa. The only ABA named in that study was the anystid *Chaussieria*.

Read et al. (2006) obtained a quantitative estimate of the feeding of *S. scimitus* on nematodes. They sequenced fragments of cytochrome oxidase I (COI) mtDNA and designed species-specific primers that amplified 154-, and 203-bp fragments for each nematode species.

A qualitative molecular method for detecting the nematode remains within the bodies of their predators was developed by Read et al. (2006), using specific nematode primers. Heidemann et al. (2011), who used this approach, noted that detection time for various prey may differ between nematodes, and determined the extent of nematophagy and detritophagy of several species.

The detection of secondary predators (e.g. predators of predators), by amplified prey DNA, and then that of the first predator, in which the prey DNA was detected, was described by Sheppard et al. (2005). DNA was found in the secondary predator up to eight hours after the first had fed on the prey. King et al. (2008) reviewed methods for DNA-based approaches to the molecular analysis of predation, including collecting, preservation and preparation of material, designing primers and so on.

**The future use and application of ABAs**

Phytophagous mites were formerly the main target of predatory Acari, but with the realization that ABAs can also reduce the damage of insect pests, e.g. thrips and whiteflies, as well as nematodes, weeds and even fungi, the spectrum of pernicious targets has expanded, and can be expected to widen further in the future. The above summation attempted to present the current ABA situation in order to try and indicate future possibilities and trends. The oft-repeated cliché that additional ABAs (whether indigenous and/or exotic) should be found and assayed (e.g. Knapp et al. 2013) still needs to be emphasized. Surveying (or prospecting) for ABAs (especially phytoseiids) in recent years has resulted in regional faunistic lists of such mites, as well as in the discovery of new species (i.e. Halliday 2005; Papadoulis et al. 2009; Kreiter et al. 2010; Barbar 2013; Döker et al. 2014 and others). Such efforts, to include non-phytoseiid ABAs also (like eriophyiids for weed control, Asadi et al. 2014), should be encouraged. Practitioners trying any of the newly-found exotics should follow the guidelines of the Convention on Biological Diversity (Cock et al. 2009), and the various biosecurity-related legislations for preventing the introduction of alien organisms. With this in mind, the classical method of BC (e.g. introduction) is still practiced (e.g. Smith et al. 2010; Maoz et al. 2011). Predicting the possible success of exotic BC agents, based on a meta-analysis of historical data, was discussed by Kimberling (2004), an approach that could be useful in predicting the outcome of intentional introductions and their possible ecological outcomes in new environments. Skirvin et al. (2002) constructed a model that indicated the importance of plant species and the spatial dynamics of mite pest and phytoseiid predator in determining the outcome of BC in ornamental crops.

Beside introduction, the other two BC modes, augmentation (e.g. Casey and Parrella 2005; Adar et al. 2014) and conservation (Kawashima and Jung 2010, and above, effect of pesticides) of ABAs, have become more common. This is due to the increasing use of indigenous ABAs (e.g. Maoz et al. 2014), and is expected to become more prevalent. The problem of the decreasing number of traditional mite taxonomists could be offset by applying molecular methods (Gaskin et al. 2011) and applying statisti-
cal methods for morphological continuous characters (Tixier 2012, 2013). Next generation sequencing (NGS) was discussed by Pompanon et al. (2012), an approach that has the potential to reveal many consumed species simultaneously (DNA metabarcoding) and to identify the species found in pooled samples.

Although most Phytoseiidae of Types II, III and IV are (within broad limits) generalists, some exceptions were noted, e.g., biotypes or more-specialized races (e.g. McMurtry 2013 et al. and Table 2). By “conditioning” or learning (Schausberger et al. 2010; Peralta-Quesada and Schausberger 2012), such ABAs might become more specialized “biopesticides”, being attracted to certain prey (or to their host-plants). Choe et al. (2012) recently found that many free-living and parasitic nematodes produce small molecules (ascarosides), used as species-specific signaling for mate finding and aggregation. Conditioning soil predators to becoming attracted to these compounds could enhance their efficacy as nematophagous. Subterranean tulip bulbs infested by eriophyid mites produce odours that attract predatory mites (Aratchige et al. 2004), a finding that suggests a new approach for exploiting ABAs in the soil.

The efficacy and rearing of ABAs (especially phytoseiids) can be increased by mechanical mite dispensers (Opit et al. 2005), by artificial diets (Nguyen et al. 2014), by developing methods to predict future phytoseiid numbers on crops (Kawashima and Jung 2010), by providing on-plant shelters, like domatia, and by modeling (e.g. Skirvin et al. 2002).

Determining the role of secondary predators, as noted, would help in establishing the actual efficacy of any ABAs whose pest controlling role has been questioned (Roberts et al. 2011).

Interactions between ABAs and other BC factors, whether resulting in IGP or other interactions, bear further studies, but the addition of acaropathogenic fungi to ABAs seems to reduce overall control.

The option of introducing ABAs (indigenous and/or exotic) against soil pests may be hindered by the specific conditions pertaining there (e.g. structure and texture, moisture, pH, salinity as well as by resource competition). On the other hand, soil cover (non-crop vegetation or mulch, Navarro-Camposa et al. 2012) increases the numbers of natural enemies, including ABAs (Tsitilas et al. 2010). In light of the beneficial effect of AM fungi on ABAs (Schausberger et al. 2012), promoting these fungi along with the relevant plant communities may increase predator attraction to pest infested plants (Bennett 2012).

The use of various mites, not necessarily ABAs, as vectors of entomophagous and/or nematophagous fungi and/or viral weed diseases affecting pests is another potential option. In the context of IPM, the effects of various pesticides and their side-effects (including those of plant origin), by standardized toxicological tests (Bernard et al. 2004) is to be continued.

The effects of new lighting technologies on plants, and their effects on herbivorous and beneficial arthropods in high-technology greenhouse production (Vänninen et al. 2010), may change the impact of ABAs in that environment.

The increasing use of GMO plants requires more studies about their effects on pests and (in the present context) on ABAs. The few cases noted are probably far from the full picture. The option of using GMO plants to produce more ABA-attracting volatiles (Kos et al. 2009), suggests yet another approach.

Most efficient ABAs are known to affect mite pests, which beg the question whether ABAs may also reduce the numbers of insect pests, to similar extents. The considerable damage caused by the mites Varroa and Acarapis to honey bee colonies (Sammataro et al. 2000) suggests that other Acari could also seriously reduce insect pest populations.

REFERENCES


Adar E., Inbar M., Gal S., Gan-Mor S., Palevsky E. 2014 — Pollen on-twine for food provisioning and oviposition


Gerson U.


Döker I., Stathakis T.I., Kazak C., Kartuk K., Papadoulis, G.Th. 2014 — Four new records and two new species of Phytoseiidae (Acari: Mesostigmata) from Turkey, with a key to the Turkish species — Zootaxa, 3827: 331-342.


Gerson U.


Lin J., Nakao H., Saito Y. 2002 — A new species of Tarsonemus (Acari: Tarsonemidae), preying on eggs of


Torres J.B., Ruberson J.R. 2008 — Interactions of *Bacillus thuringiensis* Cry1Ac toxin in genetically engineered cotton with predatory heteropterans — Transgenic Res., 17: 345-354. doi:10.1007/s11248-007-9109-8


Gerson U. Acarologia is under free license. This open-access article is distributed under the terms of the Creative Commons-BY-NC-ND which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original author and source are credited.