

HOW TO ENHANCE PEST CONTROL BY GENERALIST PREDATORY MITES IN GREENHOUSE CROPS

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ABSTRACT.

Generalist predatory mites are increasingly used in greenhouse crops to control small insects and mites. The success of these predators is strongly affected by crop characteristics. Crops that provide non-prey food facilitate predator establishment. Here we review three methods for improving establishment of generalist predatory mites in greenhouse crops based on (1) crop diversity, (2) pest diversity and (3) alternative food. The underlying theory about food web interactions is discussed in order to predict the effect of these methods on biological control. Furthermore, we show preliminary results of experiments in which alternative food was added to enhance predator establishment.

INTRODUCTION.

Integrated pest management has increasingly included generalist predators feeding on multiple prey, particularly predatory mites (Gerson & Weintraub 2007; Sabelis *et al.* 2008). Recently, the generalist predatory mite *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae) has been introduced for controlling both thrips (Messelink *et al.* 2006) and whiteflies (Nomikou *et al.* 2002), with possible side-effects on other pests. This has been a break-through in IPM greenhouse crops, in particular in the Mediterranean area (see www.allaboutswirskii.com). Generalist predators often feed on pollen and can therefore easily establish in crops that produce suitable pollen, such as sweet pepper (Ramakers 1990). However, most greenhouse crops lack such food and predator introduction must be timed to the presence of phytophagous arthropods. As a result, a temporary peak of the pest population has to be tolerated. This is particularly a problem in ornamental crops, where thresholds of damage are extremely low. Growers therefore frequently introduce high doses of predatory mites. Methods for improving establishment and performance of these predatory mites would lower the costs of biological control and improve efficacy. Here, we review three possible methods for pest control using generalist predatory mites in greenhouse crops.

Crop Diversity.

Due to strict measurements concerning hygiene, the use of soil-less substrates and closed greenhouses, most modern greenhouse crops can be considered as highly simplified ecosystems. The lack of biodiversity hampers establishment of many natural enemies. Experimental studies in outdoor crops show that creating crop diversity with strips of flowering plants or habitats that offer shelter can increase natural enemy abundance, diversity and fitness (Landis *et al.* 2000). The question is whether crop diversity can be applied in modern greenhouse crops for improving pest

control. Mixed cropping is applied on a small scale by organic growers of greenhouse vegetables, but without clear advantages for pest control because predators stay close to their favorite crop (Messelink, pers. obs.). Furthermore, the practical and economic disadvantages of mixed cropping are such that its application is simply out of question in most modern greenhouses. A less drastic method to create crop diversity is the use of banker plants. One elegant system that has been developed for predatory mites uses the castor bean plant, *Ricinus communis* L. (Euphorbiaceae). This plant is an excellent banker plant because it produces enormous amounts of pollen and extra-floral nectar (Van Rijn & Tanigoshi 1999a), and positive results have been achieved with it (Ramakers & Voet 1996). *Ricinus* was originally used for the introduction of *Iphiseius degenerans* (Berlese) (Acari: Phytoseiidae), but other phytoseiid predatory mite species such as *A. swirskii* and *Euseius ovalis* (Evans) (Acari: Phytoseiidae) can also be easily reared on these plants. Application of banker plants in greenhouses is limited until now, but we consider castor bean plants as a perfect tool for introducing predatory mites in greenhouse crops where they would otherwise establish with difficulty, in particular for those predatory mites that are hard to mass produce and thus expensive. Castor bean plants might play an important role in future introductions of “new” generalist predatory mites.

Pest Diversity.

A second concept for improving pest control by generalist predatory mites is based on pest diversity. The use of generalist predators for biological control can result in predator-mediated interactions among prey species that otherwise might not interact (Janssen *et al.* 1998; Harmon & Andow 2004). If, for example, the density of one prey species increases, the density of the shared predator also increases and, consequently, the second species decreases in abundance. Holt (1977) has called these interactions apparent competition, because it looks as if the two species compete for a shared resource, whereas in fact it is the shared predator that mediates this interaction. The theory of apparent competition is based on equilibrium dynamics, hence, the effect of a shared natural enemy might be different in the short-term, when equilibria have not been reached. Indeed, increases of one prey species can result in short-term satiation of the shared predator, resulting in a negative effect on the control of the second pest (so-called apparent mutualism, Abrams & Matsuda 1996). The duration of these short-term effects clearly depends on the ecology of the predator. Especially for predators with a long reproduction time this negative effect can be serious (Koss & Snyder 2005; Symondson *et al.* 2006). The challenge for biological control is to apply theory on these predator-mediated interactions between pest species in such a way that biological control is enhanced. Two recent studies with generalist predatory mites indeed showed that pest control can be enhanced by predator-mediated indirect pest interactions. The presence of thrips in a cucumber crop resulted in a considerable improvement of the control of whiteflies (Messelink *et al.* 2008). Spider mite control was also much better in the presence of thrips or whiteflies separately, but the best when both thrips and whiteflies were present (Messelink *et al. in prep*). Disruption of biological control through predator satiation occurred when high releases of whiteflies delayed the control of thrips by *A. swirskii* (Messelink & Janssen 2008).

Pest diversity can also be advantageous when natural enemies grow and reproduce better on a diet consisting of several pests than on single pest diets. For

example, lady beetles have been shown to benefit from diets consisting of mixed aphids (Evans *et al.* 1999). Generalist predatory mites also benefit from mixed pest diets; juvenile development of the predatory mite *A. swirskii* was significantly improved on a mix of thrips and whiteflies compared to a single pest diet (Messelink *et al.* 2008). Such mixed diet effects are believed to amplify the effects of apparent competition. With respect to biological control, growers might thus consider allowing or even introducing some kind of pest diversity in order to enhance control. Such releases of pest species are not a totally foreign concept for greenhouse growers. The “pest-in-first” strategy with spider mites to enhance control by *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) has been successfully applied now for many years by sweet pepper growers (Hussey *et al.* 1965). Pest diversity might not only result in predator-mediated interactions, but also in plant-mediated interactions among pest species. The attack of a plant by one pest species can induce resistance mechanisms in the plant, which subsequently slows the development of a second pest species (Karban & Carey 1984). Theory and empirical data about apparent competition, mixed diets and induced plant defences, encourage us to further study the role of pest diversity in biological control and develop practical methods which can be applied by growers.

Alternative Food.

Generalist predatory mites supplement their diet with non-pest food such as pollen and honeydew (McMurtry & Croft 1997). This offers opportunities to improve establishment of these predators by artificially adding alternative food sources. However, it is not immediately obvious that adding alternative food will also result in reduced pest densities. Theory concerning shared predators (discussed above under *Pest diversity*) is also relevant for alternative non-prey food. Alternative food might decrease the per capita consumption of the target pest prey through predator satiation or may even result in the predators switching to the alternative food, which was shown for the mite *Euseius scutalis* (Athias-Henriot) (Acari: Phytoseiidae) when offered a mix of whiteflies and pollen (Nomikou *et al.* 2004). The alternative food source might also be beneficial for the pest species itself, like pollen is for thrips (Hulshof *et al.* 2003). Shared predation theory predicts, however, that alternative food will always reduce equilibrium pest densities as long as the alternative food source has a positive effect on predator reproduction and survival. Thus short-term negative effects of predator satiation, predator switching or even increased pest reproduction do finally not matter, as this will be compensated by predation from a larger predator population due to the predator’s numerical response to the alternative food (Van Baalen *et al.* 2001; Van Rijn *et al.* 2002). The theory is based on long-term equilibrium dynamics, but when dynamics show fluctuations, apparent mutualism will occur at longer time-scales as well (Abrams *et al.* 1998). Because growing seasons for most crops are short, it is thus important to focus on the non-equilibrium dynamics and determine the circumstances under which the addition of alternative food sources will improve pest control.

Table 1. Reported effects of non-prey food on generalist predatory mites (Acari: Phytoseiidae).

Predatory mite species*	food source	Reported effects	Reference
<i>E. hibisci</i> <i>T. limonicus</i>	Yeast hydrolysate + Molasses or sucrose	Increased longevity, oviposition rate ca. 30% of pollen diet	McMurtry & Scriven 1966
<i>E. hibisci</i> <i>I. degenerans</i> <i>T. limonicus</i>	Mixture of honey, yeast, sugar, egg yolk and casein hydrolysate	Oviposition rate 6-51% of oviposition rates on natural diets	Kennett & Hamai 1980
<i>A. swirskii</i>	Mixture of yeast, milk powder, amino acids, vitamins, sugars and antibiotics	Increased longevity, oviposition rate ca. 50% of pollen diet	Abou-Awad <i>et al.</i> 1992
<i>E. ovalis</i>	Paraffin-diet-chips, based on diet of Kenneth and Hamai (1980)	Low oviposition rate, high juvenile mortality, shorter longevity compared to prey	Sih <i>et al.</i> 1993
<i>N. cucumeris</i>	Protein powders based on casein, soya or Deccan grass	Low oviposition rate	Matsuo <i>et al.</i> 2003
<i>I. degenerans</i>	Sterilized flour moth eggs (<i>Ephestia kuehniella</i>)	developmental time slightly higher than on pollen diet	Vantornhout <i>et al.</i> 2004
<i>I. degenerans</i>	Decapsulated brine shrimp cysts (<i>Artemia franciscana</i>)	developmental time comparable to pollen diet	Vantornhout <i>et al.</i> 2004
<i>N. californicus</i>	Honey, sucrose, tryptone, yeast extract and egg yolk	Low oviposition rate, excellent survival (up to 90 days)	Ogawa & Osakabe 2008

* Names of the genera: A. = *Amblyseius*, E. = *Euseius*, I. = *Iphiseius*, N. = *Neoseiulus*, T. = *Typhlodromalus*.

Many studies report that pollen is an excellent alternative food source for predatory mite species (Van Rijn & Tanigoshi 1999b). Other food sources, such as nectar or honeydew, do not allow for predator reproduction when consumed alone (McMurtry & Scriven 1966; Van Rijn & Tanigoshi 1999a). The many studies on pollen however have not resulted in pollen-based products that growers can apply in greenhouses. One simple reason might be that collecting pollen is labour-intensive and thus expensive. An alternative could be to use bee-collected pollen, which are commercially available at low prices. Sprays of bee-collected pollen was shown to increase the numbers of a predatory mite (Ramakers 1995). However, bee-collected pollen is contaminated with free sugars, and this resulted in fungus growth in humid greenhouses. Many artificial food sources other than pollen seem to have potential for enhancing establishment of predatory mites, but were only investigated in the laboratory (Table 1). In this paper we show preliminary results of the effect of non-prey alternative food for enhancing establishment of generalist predatory mites in a greenhouse crop.

MATERIALS AND METHODS.

Alternative Food Sources and Cultures.

Six sources of alternative food were selected: (1) cattail pollen (*Typha latifolia* L. (Typhaceae)), (2) dried and grinded bee-collected pollen of Cistaceae (www.pollen-online.com), (3) a mixture of yeast, glucose and soya powder, (4) *Carpoglyphus lactis* (Linnaeus) (Acari: Carpoglyphidae), the sugar mite on which *A. swirskii* is mass produced, (5) *C. lactis* plus a mixture of yeast and glucose and (6) Aminofeed®, a commercial product based on proteins and sugars (3% solution). We measured oviposition of *A. swirskii* in the laboratory and population dynamics in a greenhouse. Predatory mites for the laboratory experiments were reared on cattail pollen; for the greenhouse experiment they were reared on bran and *C. lactis*. For the greenhouse experiment we used chrysanthemum cuttings cv. "Omega Time Pink", which were planted in 12cm diameter pots in peat.

Oviposition.

The reproduction value of the selected alternative food sources was assessed in a laboratory experiment using the method of Van Rijn & Tanigoshi (1999). Young *A. swirskii* females of the same age were placed on black plastic arena's where the food sources were supplied *ad libitum*. The rate of oviposition was scored from day 4 through day 7. Eggs were removed before they hatched in order to avoid cannibalism on larvae. One replicate consisted of 12 females in one arena and each food source was replicated 4 times. The experiments were performed in a climate room at 22°C, 70% RH and a 16:8h L:D regime.

Population Dynamics.

Population development of *A. swirskii* was assessed on a chrysanthemum crop for a 6 week period on plants without or with the selected alternative food sources. The experiment was set up as a block treatment with 3 replicates. Each block consisted of one table and each plot consisted of a group of 12 plants. Contamination between plots was avoided by a barrier of overlapping sticky plates placed around the plants on the table. Tables were supplied by a standard nutrient solution. Plants of 4 weeks old, containing up to 20 leaves, were supplied with the alternative food sources. Aminofeed® was sprayed in a 3% solution in water. The sugar mite *C. lactis* was released at a density of ca. 500/plant. All other food sources were evenly distributed over the plants at a density of 40 mg/plant. This food application was repeated once after 3 weeks. Shortly after the first food application, we released 20 predatory mites of mixed age per plant. Population development of the predatory mites was followed by weekly picking of 12 leaves per plot (1 leaf/plant) and counting the number of mites under a binocular microscope. The average greenhouse temperature during the experiment was 23.5°C and the average RH was 73%.

Statistics.

For both the laboratory and greenhouse experiment, a repeated measures ANOVA with time as the random factor was performed on the data by using Genstat

(Payne *et al.* 2007). Predator densities in the greenhouse experiment and numbers of eggs in the laboratory experiment were log (x+1) transformed. Differences between treatments were tested at the 5% level using Fisher's LSD (Least Significant Difference) test.

RESULTS.

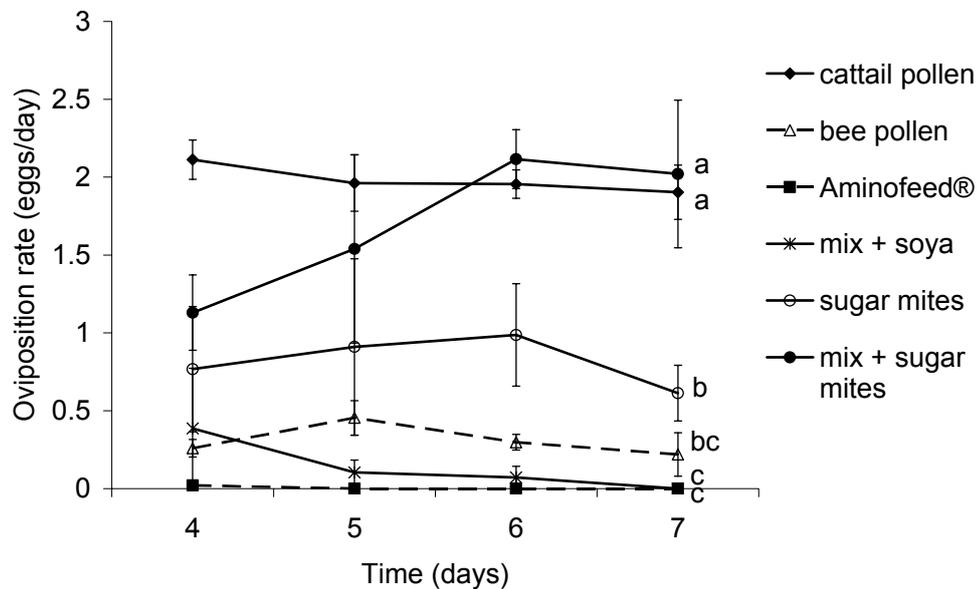


Fig. 1. Effects of alternative food sources on oviposition rates (\pm se) of the predatory mite *A. swirskii* on plastic arenas in the laboratory. Oviposition was measured daily from 4 to 7 days after transition from a diet of cattail pollen to the alternative food source. The mix stands for glucose plus yeast. Food source types followed by the same letters are not statistically different ($P < 0.05$).

There were clear and significant effects of the alternative food sources on both oviposition rate in the laboratory (Fig. 1) ($F_{(5)} = 21.44$; $P < 0.001$) and predator development in the greenhouse experiment (Fig. 2) ($F_{(6)} = 8.65$; $P < 0.001$). Cattail pollen resulted in the highest and most stable oviposition rates in the laboratory (Fig. 1), whereas in the greenhouse experiment the effects on population development were very strong, but short term (Fig. 2). Bee pollen and the diet of glucose, yeast and soya gave low oviposition rates in the laboratory, but significant effects on population establishment in the greenhouse experiment. The addition of yeast and glucose to a diet of sugar mites (*C. lactis*) increased both oviposition and predator densities on the chrysanthemum plants. Predators did not oviposit with Aminofeed® as food source, but population establishment was significantly lower in the greenhouse experiment (Figs. 1, 2).

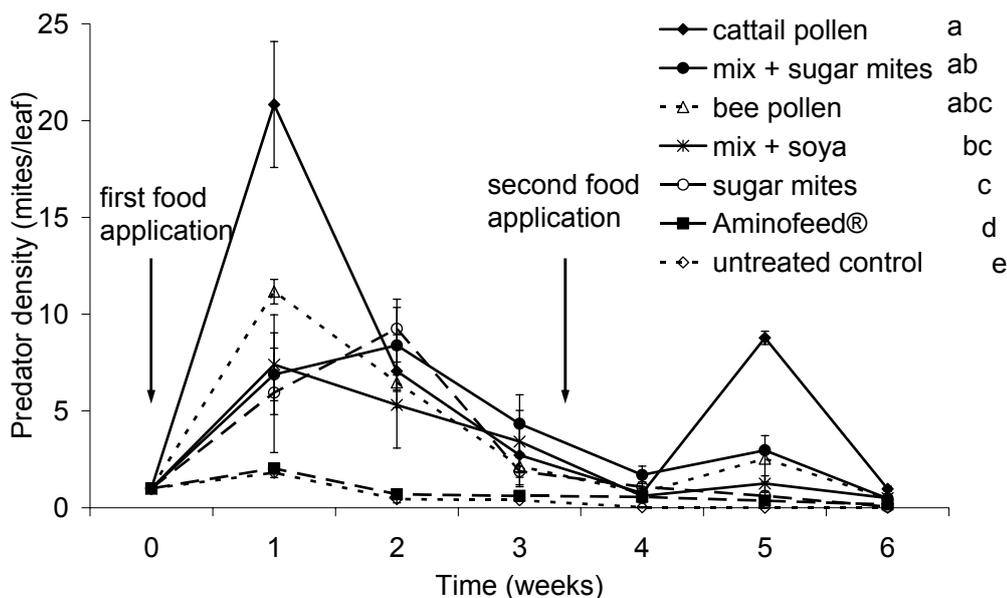


Fig. 2. Effects of the supply of alternative food sources on densities of the predatory mite *A. swirskii* in a non-flowering chrysanthemum crop. Shown are average (\pm se) numbers of predatory mites per chrysanthemum leaf. The mix stands for glucose and yeast. Food source types followed by the same letters are not statistically different ($P < 0.05$).

DISCUSSION.

This study showed that enhancing establishment of generalist predatory mites on plants by adding factitious alternative food sources is a promising method. Many studies have evaluated the nutritional value of such food sources before, but evaluations on the target crop itself are scarce. Recently, Ogawa & Osakabe (2008) suggested using artificial diets to maintain predatory mite populations during periods when herbivore prey are scarce. The results of our experiments are in line with this idea. Bee pollen and a mixture of yeast, glucose and soya were less suitable for predator reproduction, but they look promising for maintaining populations on plants. Cattail pollen was, on the other hand, very suitable for reproduction, but the effects on population development were over time not better than the bee pollen or the mixture of yeast, glucose and soya. Adding sugar mites to plants as alternative food for the predatory mites seems to offer possibilities, as was suggested before by Hoogerbrugge *et al.* (2008). The addition of yeast and glucose significantly improved this effect, probably because both the predatory mites and sugar mites feed on this supplemental food. The laboratory experiment also showed that oviposition on a diet of sugar mites plus yeast and glucose increased with time. A possible explanation is that the young sugar mite stages that were produced on the sugar and yeast diet are more suitable as food for *A. swirskii* than the older stages.

Application of non-prey food sources might not only be important for maintaining predator populations in periods when pests are not present, but also to supplement diets of prey-species in order to increase reproduction. It is known that some invertebrate predators can forage selectively for protein and lipids to redress specific

nutritional imbalances (Mayntz *et al.* 2005). Alternative food sources that supplement prey diets might then even be preferred.

CONCLUSIONS.

Both theory and empirical data about alternative food, offer new possibilities to enhance pest control with generalist predatory mites. Future research should focus on the short-term effects of alternative food (either supplied by banker plants, pest diversity, or factitious food) on biological control of the target pest species.

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