

Biological control of mealybugs with lacewing larvae is affected by the presence and type of supplemental prey

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Received: 26 January 2016 / Accepted: 15 April 2016 / Published online: 22 April 2016
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Abstract The diversity of prey and food sources in crops has a major effect on biological pest control by generalist predators. In this study, we tested if and how supplemental prey or food affects the control of the citrus mealybug *Planococcus citri* (Risso) by larvae of the green lacewing *Chrysoperla lucasina* (Lacroix). The larvae of this predator are the only stage that feed on prey, thus ideally the supplemental food should result in high larval survival but a low developmental rate. Juvenile survival and developmental time of lacewing larvae were measured on various food items, either alone or mixed with mealybugs. Mealybugs were a suboptimal prey: up to 50 % of the lacewing larvae died before they reached the pupal stage and the developmental time was relatively long when feeding exclusively on mealybugs. Mixing mealybugs with supplemental prey increased larval survival, but also reduced larval developmental time and thereby the period in which the larvae could prey on mealybugs. Moreover, adding eggs of *Ephestia kuehniella* Zeller,

which appeared to be of high quality for lacewings, reduced the consumption of mealybugs by lacewing larvae in the laboratory. The addition of the prey mite *Acarus siro* (L.) also reduced larval mortality, but did not reduce mealybug predation rates by lacewing larvae. Greenhouse trials showed better mealybug control by lacewing larvae with supplemental prey of low quality (prey mites) rather than alternative prey of high quality (*Ephestia* eggs). In conclusion, biological control of mealybugs by lacewing larvae was strongly affected by the nutritional quality of the supplemental food source.

Keywords *Planococcus citri* · *Chrysoperla lucasina* · Biological control · Mixed diets

Introduction

Generalist predators are important natural enemies for biological pest control in several agricultural cropping systems (Messelink et al. 2012b; Settle et al. 1996; Symondson et al. 2002). They often establish well in a crop by feeding on several species of pests but also by exploiting a variety of other resources such as non-pest prey or plant-provided food (Wäckers et al. 2005). Because of these characteristics, the diversity of prey and other food sources in crops has a major effect on biological pest control by generalist predators through several mechanisms (Harwood et al. 2009; Messelink

Handling Editor: Patrick De Clearcq.

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et al. 2012b; Symondson et al. 2002). For example, the availability of more prey or food will affect predator densities through apparent competition, which can result in enhanced pest control (Hanna et al. 1997; Holt and Lawton 1994; Messelink et al. 2008). Also, predators may have higher performance on mixed diets than on single-resource diets (Evans et al. 1999; Marques et al. 2015; Messelink et al. 2008; Muñoz-Cárdenas et al. 2014; Oelbermann and Scheu 2002; Toft 2005). Thus, mixed diets may boost predator populations and thereby result in enhanced pest control (Messelink et al. 2008). Furthermore, mixed diets may also result in a longer residence time of predators in patches of prey with a suboptimal nutritional value, as imbalanced diets are known to induce nutrient specific foraging to balance their diets (Jensen et al. 2012; Mayntz et al. 2005).

However, the presence of multiple prey may also have negative effects on biological control with generalist predators. Predators may switch to more abundant or more preferred alternative prey instead of feeding on the pests (Murdoch 1969), or the presence of other food sources may result in predator satiation (apparent mutualism) (Abrams and Matsuda 1996), which also releases pests from predation. Indeed, many studies have shown reduced predation rates on a target pest in the presence of alternative prey or food (Eubanks and Denno 2000; Koss and Snyder 2005; Madsen et al. 2004; Symondson et al. 2006). Hence, both the abundance and the nutritional value of the alternative prey will influence the control of the target pest (Eubanks and Denno 2000; Venzon et al. 2002). Thus, the short-term effect of adding alternative prey to a resident predator–prey system will depend on the quality of the alternative prey and the prey preference of the predator. This is especially relevant for biological control systems that exist for a limited period and the dynamics of pests and natural enemies are often transient (van Veen et al. 2006).

Here, we studied the effect of the addition of supplemental food of high and low quality on the transient dynamics of an arthropod predator–prey system. The target pest was the citrus mealybug *Planococcus citri* (Risso), which is a highly polyphagous pest of ornamental plants such as roses, gerbera and orchids, citrus, grapevine and coffee, and increasingly occurs in greenhouse ornamentals (Blumberg and van Driesche 2001; Messelink 2014). It feeds by sucking plant sap from stems, branches and leaves,

resulting in wilted, distorted, and yellowed (chlorotic) leaves, premature leaf drop, stunted growth, and occasional death of infested plants or plant parts (Godfrey et al. 2002). This pest increasingly occurs in greenhouse ornamentals such as roses, gerbera and orchids (Messelink 2014). Lacewing larvae are potential candidates to apply to the so-called “hot spots” of mealybugs in greenhouse crops. Larvae of some lacewing species were shown to feed on all stages of citrus mealybugs (Bezerra et al. 2006) and earlier studies showed promising control of mealybugs with green lacewing larvae (Doutt and Hagen 1949, 1950; Goolsby et al. 2000). However, mealybugs may not be the most suitable and preferred prey of lacewing larvae. In this study, we therefore tested the suitability of mealybugs as prey for larvae of *Chrysoperla lucasina* (Lacroix), a species of the carnea-group of *Chrysoperla* green lacewings (Henry et al. 1996), and whether other prey or food sources might enhance lacewing survival. A longer life span of lacewing larvae may increase their per capita consumption of mealybugs, thus improving biological control. However, when the supplemental prey is of high quality (in terms of survival, developmental time or reproduction) and is actually preferred by the lacewing larvae, their addition may result in decreased mealybug control. Hence, supplemental food could have both positive and negative short-term effects on the biological control of mealybugs, and these effects would strongly depend on the quality of the supplemental food. To test this, we first studied the effect of various supplemental prey and food sources, alone and combined with mealybugs, on juvenile survival and development of lacewings. Food sources with a low and high nutritional value were then tested in the laboratory and in a greenhouse crop to evaluate the effects on predation rates and control of mealybugs.

Materials and methods

Rearing of mealybugs and lacewings

A colony of the green lacewing *C. lucasina* was established in 2009 from eggs collected in a sweet pepper crop at Wageningen UR Greenhouse Horticulture in Bleiswijk, The Netherlands. It was reared in plastic boxes (ø 26 cm, 26.5 cm high) in climate chambers at 25 °C, 70 % RH and a photoperiod of

16:8 h (L:D). Larvae were fed with sterilized eggs of *Ephestia kuehniella* Zeller, mixed with buckwheat hulls to provide shelter for larvae, thus reducing cannibalism. Adult lacewings were put in separate boxes provided with corn pollen and paper towels soaked in water + honey as food sources and jute ropes as oviposition substrates. Ropes with eggs were collected from these boxes to start new cultures. The mealybug *P. citri* was reared on potato sprouts in a greenhouse compartment with a minimum temperature of 20 °C and 80 % RH.

Prey species and food sources

Various prey species and other food types were tested in laboratory and greenhouse trials. The red phenotype of the peach aphid *Myzus persicae* (Sulzer) was reared on sweet pepper plants cv. Spider in a separate greenhouse compartment. The flour mite *Acarus siro* (L.) was reared in the laboratory on wheat bran following Ramakers and van Lieburg (1982). They were provided with baker's yeast as food when used in experiments. Supplemental dead prey were sterilized eggs of *E. kuehniella* (Biobest N.V., Westerlo, Belgium), stored at -20 °C, and freeze-dried decapsulated cysts of *Artemia franciscana* Kellogg (Smulders wholesale, Artemia quick HS aqua, Ulestraten, The Netherlands), stored at room temperature. Cattail pollen (*Typha latifolia* L.) was collected along ditches in Bleiswijk, The Netherlands, dried and stored at -20 °C for six months before use.

Effects of food on lacewing juvenile development and survival

Individual first-instar *C. lucasina* were transferred shortly after hatching from eggs with a fine paintbrush to small cylindrical plastic boxes (Ø 3.5- 4 cm × 3.5 cm) with lids with a mesh-covered hole (size 80 µm) for ventilation. Food sources added to these boxes every two days were: (a) 80–100 mixed stages of peach aphids; (b) 20–30 second and third stages of the mealybug *P. citri*; (c) 150–200 mixed stages of *Acarus* with bran and yeast (0.015 g); (d) *Ephestia* eggs (0.05 g); (e) *Artemia* cysts (0.05 g); (f) cattail pollen (0.05 g). The same amounts of *Acarus*, *Ephestia* eggs, *Artemia* cysts and pollen were also tested together with mealybug larvae. Two hulls of buckwheat were added to each box as shelter for lacewing

larvae. Survival and development was recorded every two days before refreshing the food (removing all old food). Except for pollen and *Artemia* cysts, each diet (treatment) was replicated 55 times (individual larvae) in five blocks of 9, 8, 13, 16 and 9 replicates respectively. The treatments with pollen or *Artemia* cysts alone each had only 17 replicates, because it became clear that larvae did not survive on either of these food sources alone. The experiment was carried out at 25 °C, 70 % RH and a photoperiod of 16:8 h (L:D). Because only lacewing larvae prey on mealybugs, we aimed to maintaining a population of these larvae as long as possible through selecting of food that would result in increased survival but not in rapid pupation. We therefore used a Cox proportional hazards model (package survival of R, Therneau 2013) to test for differences in the cumulative proportion of larvae through time, with larvae disappearing either because they died or because they pupated. Contrasts among diets were assessed with the multcomp package (Hothorn et al. 2008) with a Tukey HSD. Differences in developmental time from larva to pupa among treatments were analysed with a GLM with a gamma error distribution and a reciprocal link function.

Predation rates

Based on the previous description, we selected supplemental food sources of high (*E. kuehniella* eggs) and low (*A. siro*) quality and tested how they affected predation rates of lacewing larvae on mealybugs. To produce a cohort of second instars, we collected lacewing eggs with a maximum age of 20 h and reared them on *Ephestia* eggs until the second larval stage, after which they were put in separate plastic boxes, as above. Ideally, the previous diet of the larvae should have been different than *Ephestia* eggs to exclude effects of rearing history on food preferences. However, because larvae are commercially produced on *Ephestia* eggs, we decided to use the same diet to mimic common practice. Predation of mealybug larvae was compared among three treatments: (a) only mealybug larvae; (b) mealybug larvae + *Ephestia* eggs (0.01 g); and (c) mealybug larvae + *Acarus* (>50 individuals). Each box was provided with second instar mealybugs, ten mealybug larvae on the first day, but because some predators ate all, this was increased to 20 per box from day 2 on. Lacewing larvae were transferred to a new box with

the same treatment after the first day. Predation rates of mealybug larvae were assessed under a binocular microscope (40×). Predation rates were repeated measures and were analysed with a linear mixed effects model [lme of the package nlme, (Pinheiro et al. 2014)] with square-root transformed numbers of mealybug larvae consumed as dependent variable, treatment and time as fixed factors and the individual lacewing larva as a random factor. The significance of the effect of diet per day was tested with a generalized linear model with a Poisson error distribution and a log link function, and contrasts among treatments were assessed using the package multcomp (Hothorn et al. 2008).

Greenhouse trial with a single release of predators

A greenhouse trial was carried out to investigate how additional prey affected the control of mealybugs by a single release of lacewing larvae. Potted rose plants cv Flamingo Jewel (De Ruiter Innovations B.V., Amstelveen, The Netherlands) were grown on peat in 6 l pots (Ø 30 cm) without insecticides, but regular applications of the fungicide dodemorph acetate (Meltatox[®], BASF) were needed against powdery mildew. Twenty-four 20-week-old plants were placed on benches (1.5 × 4 m²), three plants on each bench. Plants were provided with a standard nutrient solution for rose plants with an ebb-and-flow irrigation drain system (2–3 times a week). Three weeks before releasing the lacewings, two mealybug females carrying an egg sac were placed in a leaf axil of each plant. An extra female with an egg sac was released two weeks later to obtain mealybug populations with different developmental stages. This resulted in an average infestation of 21 (±2.7 SE) first and second instar mealybugs per plant three weeks after the first release.

Subsequently, the following treatments were applied, each with six replicates (plants): (a) untreated (only mealybugs), (b) ten second instars (L2) of *C. lucasina*, (c) ten L2 of *C. lucasina* + 0.5 g sterilized eggs of *E. kuehniella*, and (d) ten L2 of *C. lucasina* + c. 1200 *A. siro* (plus 0.2 g bran and 0.05 g yeast). Mites, *Ephestia* eggs and lacewing larvae were distributed on the tops of the plants. Plants were isolated from each other by a circle of Tanglefoot[®] insect glue (diameter 1 m). Entrapping of lacewing larvae in the glue was recorded daily. Temperature (average 20.1 °C) and RH (average 71 %) in the compartment were registered every 5 min throughout the experiment with a climate

recorder (Hoogendoorn Growth Management). Densities of mealybugs and lacewing larvae per plant were assessed two weeks after the release of the lacewings. We assumed that the majority of lacewing larvae had then either died or pupated. Log-transformed densities of mealybugs were analysed as response variable in R with a linear mixed effects model (Pinheiro et al. 2014) with treatment and time as fixed factors and plant as a random factor because of repeated measures. Per week, differences among treatments were compared with a generalized linear model (GLM) with treatment as factor, a Poisson error distribution and a reciprocal link function. Contrasts among treatments were assessed with the package multcomp (Tukey HSD, Hothorn et al. 2008).

Greenhouse trial with multiple predator releases

A second greenhouse trial was set up similar to the first greenhouse trial, but with multiple releases of lacewing larvae to study effects of supplemental food on the control of mealybugs over a longer period. Plants received one mealybug female with an egg sac to a leaf axil every week during three weeks, resulting in an average infestation of 52 (±3.2 SE) larvae of mixed age per plant five weeks after the first release. Two additional treatments with extra food but without lacewing larvae were added to study direct effects of the prey on mealybug densities. This resulted in the following treatments: (a) mealybugs only, (b) mealybugs with *Ephestia* eggs, (c) mealybugs with *Acarus*, (d) mealybugs with larvae of *C. lucasina*, (e) mealybugs with larvae of *C. lucasina* + *Ephestia* eggs and (f) mealybugs with larvae of *C. lucasina* + *Acarus*. Second instar *C. lucasina* were released three times with a weekly interval in densities of 12, 28 and 20 per plant respectively. Each treatment was replicated seven times, (42 plants in total, distributed over 14 benches, three plants per bench). Two replicates of the treatment with *Acarus* only were lost due to an unintended release of lacewing larvae.

Food sources were added at the same time as the lacewing larvae. Ca. 1600 *Acarus* (+0.2 g bran and 0.05 g yeast) were added per plant. *Ephestia* eggs were added at 0.5 g plant⁻¹. These amounts were doubled at the second and third release, as more lacewings were released. The average temperature was 20.0 °C and the average RH 70 %. Densities of mealybugs and lacewings per plants were assessed

weekly during five weeks, from one week after the first predator release to three weeks after the last predator release. Statistical analyses were similar to those for the experiments with single predator releases, but contrasts among treatments through time were assessed with the `glht` function (package `lsmeans` of R, Tukey HSD, Lenth 2016).

Results

Effects of food on lacewing juvenile development and survival

The proportion of *C. lucasina* larvae declined over time in all treatments, either because they pupated or died. There was a significant difference in the rate of decline among treatments (Likelihood ratio test: $\chi^2 = 204.6$, d.f. = 9, $p < 0.001$, Fig. 1). Of the single diets, the cumulative proportion of larvae was highest on diets of peach aphids, mealybugs and *Acarus* (Fig. 1a). Larvae fed cattail pollen, *Artemia* cysts, or *Acarus* only did not develop to the pupal stage, but mortality occurred earlier when feeding on the first two diets than on *Acarus* (Fig. 1a). On mixed diets, the cumulative proportion of larvae through time was highest on a diet of mealybugs plus *Acarus* and mealybugs plus *Artemia* cysts (Fig. 1b), but all mixed diets showed a faster or equal decline of the proportion of *C. lucasina* larvae as when fed mealybugs alone (Fig. 1). The developmental time of lacewing larvae differed significantly according to diet (GLM, $\chi^2 = 12.7$, d.f. = 5, $p < 0.0001$, Fig. 2). Development on mealybugs alone took significantly longer than on aphids or *Ephestia* eggs alone or on mealybugs mixed with *Ephestia* eggs or *Acarus* (Fig. 2). In conclusion, mealybugs were relatively unsuitable prey for lacewing larvae. Addition of *Ephestia* eggs or *Acarus* reduced mortality, but also decreased the developmental time and thereby the period for mealybug predation.

Predation rates

The addition of supplemental prey or food affected the predation of mealybug larvae differently on two days (Fig. 3, lme, interaction of treatment with time: $F_{2,57} = 17.1$, $p < 0.001$). On the first day, there was

no significant difference in predation rates among the three treatments (Fig. 3, GLM: $\chi^2 = 0.45$, d.f. = 2, $p = 0.80$). On the second day, there was a significant effect of the supplemental food on predation of mealybugs (Fig. 3, GLM: $\chi^2 = 81.9$, d.f. = 2, $p < 0.001$). With *Ephestia* eggs, predation was significantly lower than with the other foods (Fig. 3). The presence of *Acarus* did not affect the predation rate of mealybugs.

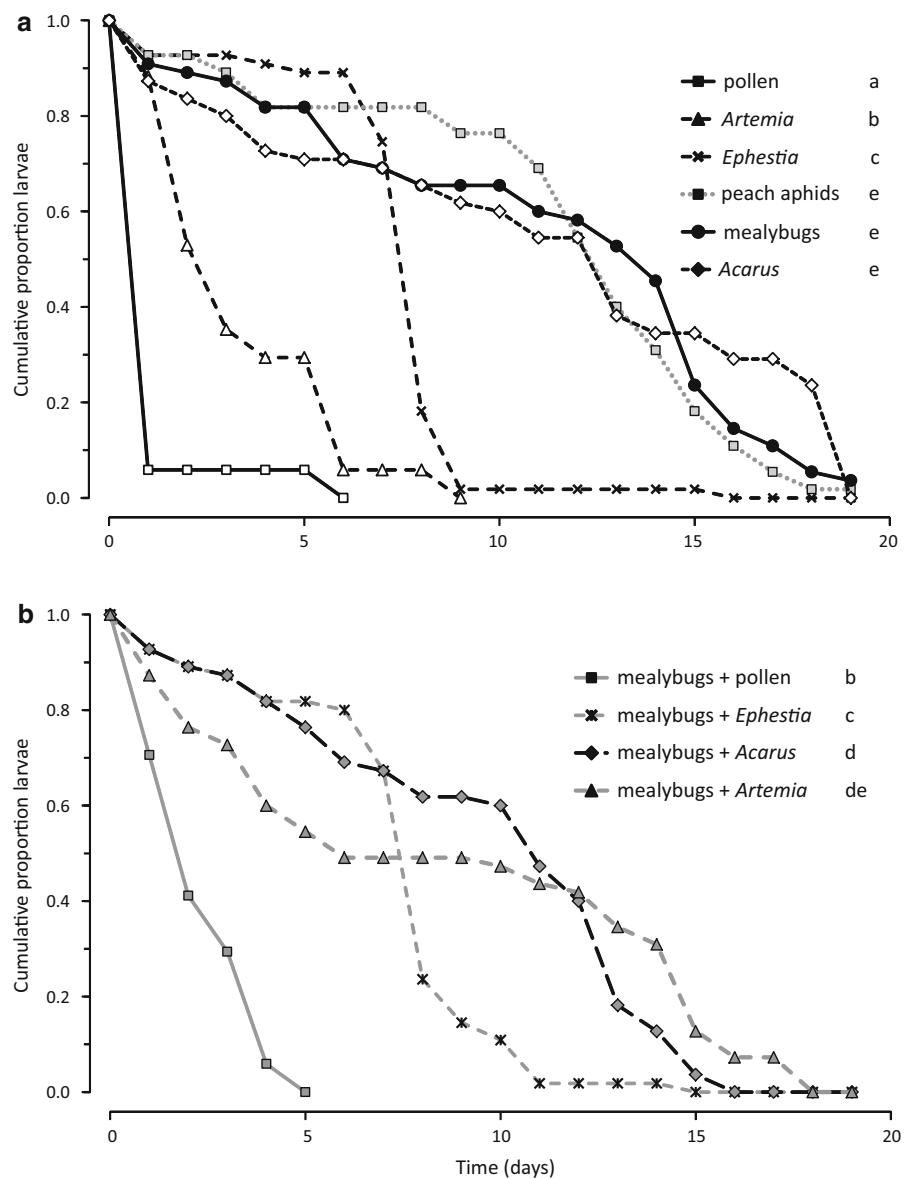
Greenhouse trial with a single release of predators

Mealybug densities differed significantly among treatments (Fig. 4, lme: $\chi^2 = 17.7$, d.f. = 3, $p < 0.001$) and with time ($\chi^2 = 23.4$, d.f. = 1, $p < 0.0001$), and the interaction between treatment and time had a marginally significant effect ($\chi^2 = 7.74$, d.f. = 3, $p = 0.052$). In both weeks, there was a significant effect of the supplemental food on mealybug densities (GLM, week 1: $\chi^2 = 216.5$, d.f. = 3, $p < 0.001$; week 2: $\chi^2 = 336.9$, d.f. = 3, $p < 0.001$). After one week, mealybug densities were highest in the absence of lacewing larvae and lowest with lacewing larvae plus *Acarus* (Fig. 4). After two weeks, the densities of mealybugs in the presence of lacewing larvae plus *Ephestia* were as high as on the plants without lacewings (Fig. 4). Densities of mealybugs on plants with lacewings plus *Acarus* and with lacewings alone did not differ significantly from each other, but did differ from the other two treatments (Fig. 4). In short, the control of mealybugs by lacewing larvae was best when *Acarus* were added as supplemental food in the first week, but equally good with or without *Acarus* in the second week. The addition of *Ephestia* eggs significantly reduced mealybug control (Fig. 4).

Greenhouse trial with multiple predator releases

Overall, there was a significant interaction between time and treatment ($F_{5,197} = 25.2$, $p < 0.0001$). This was caused by the initial densities of mealybugs being similar for all treatments, but with time, the densities diverged (Fig. 5). Mealybug densities were reduced to low levels in all treatments with lacewing larvae and the presence of supplemental prey did not significantly affect this control (Fig. 5). Addition of supplemental prey without predators did not affect mealybug densities (Fig. 5).

Fig. 1 Proportion of *Chrysoperla lucasina* larvae surviving through time when supplied with different diets. The larvae either developed into pupae or died. Diets were either *Typha* pollen, *Artemia* cysts, *Ephestia* eggs, peach aphids, mealybugs or *Acarus* (a), or combinations of mealybugs with *Typha* pollen, *Acarus*, *Artemia* cysts or *Ephestia* eggs (b). Different letters next to legends indicate significant differences among survival curves of the various treatments (a and b combined, $p < 0.05$)



Discussion

Larvae of the green lacewing *C. lucasina* were able to control citrus mealybugs on potted roses and the presence and type of supplemental prey can affect this control. Each larval stage of *C. lucasina* was able to consume and develop on mealybug larvae. Second instar lacewings showed a considerable predation rate of 8–12 mealybug larvae per day. However, larval developmental time of *C. lucasina* feeding on mealybug larvae was relatively long and about 50 % died before reaching the pupal stage, indicating that

mealybugs are not very suitable prey for lacewing larvae. Sterilized *E. kuehniella* eggs were an excellent food source for lacewing larvae, resulting in a short developmental time and low larval mortality.

The limited suitability of mealybugs as prey for lacewing larvae had consequences for their predatory behaviour and efficacy. In the laboratory, we found a reduction of predation rates when *Ephestia* eggs were added to mealybugs. The greenhouse trial with a single release of predators also showed that supplying lacewings with *Ephestia* eggs decreased the control of mealybugs. Perhaps the lacewing larvae switched to

Fig. 2 Developmental time (mean \pm SE) of *Chrysoperla lucasina* from first larval stage to pupa on different diets. Numbers in the bars indicate percentage of larval mortality of 55 individuals, except the treatments with pollen or *Artemia* cysts alone, which each had only 17 replicates. Different letters next to the bars indicate significant differences in developmental time among treatments ($p < 0.05$)

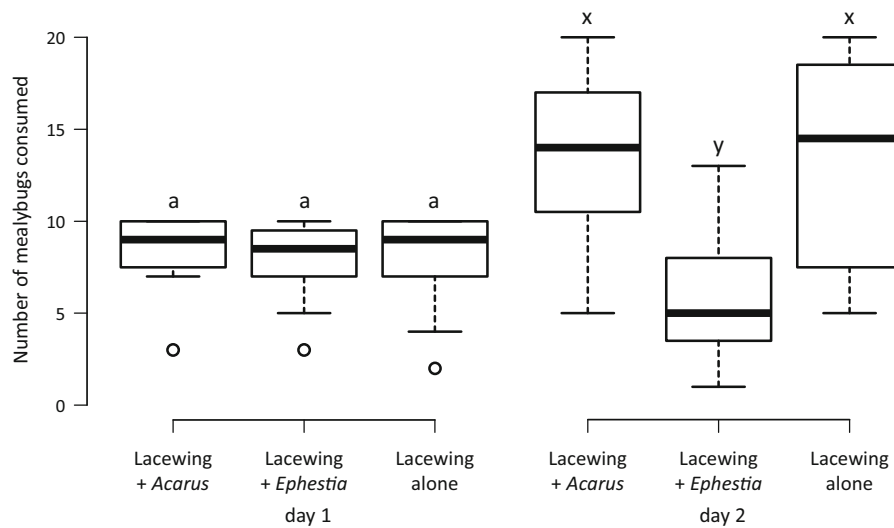
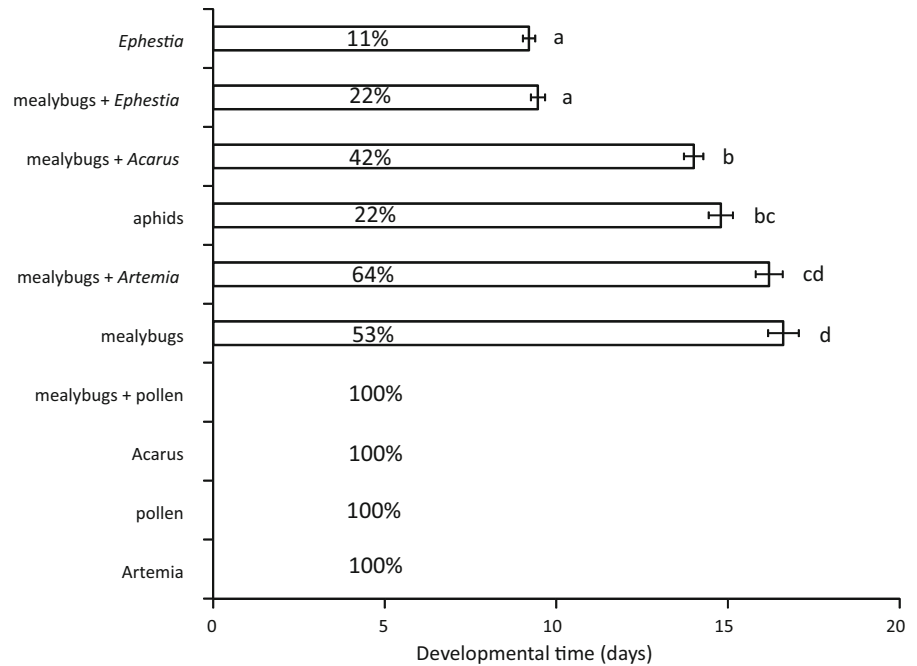


Fig. 3 Effects of supplemental prey on the consumption of mealybug larvae by second instar *Chrysoperla lucasina* in the laboratory. Shown are median predation rates (horizontal line), the 25 and 75 quartiles (box), and outliers (points) of second

instars of the mealybug *Planococcus citri* one and two days after providing the diets. Different letters above the whiskers indicate significant differences among diets within the same day (contrasts after GLM, $p < 0.05$)

the high quality supplemental prey, which in general may reduce predation on the target pest through satiation of the predators or through preferential feeding on the supplied food. This may be detrimental for pest control in the short term (Bergeson and Messina 1998; Symondson et al. 2006; van Maanen

et al. 2012). Another explanation for the reduced predation is that larvae that fed on *Ephestia* eggs had a much shorter developmental time, hence, actively prey on mealybugs for a shorter period (Fig. 2). Although a similar trend was observed, reduced mealybug control in the presence of *Ephestia* eggs

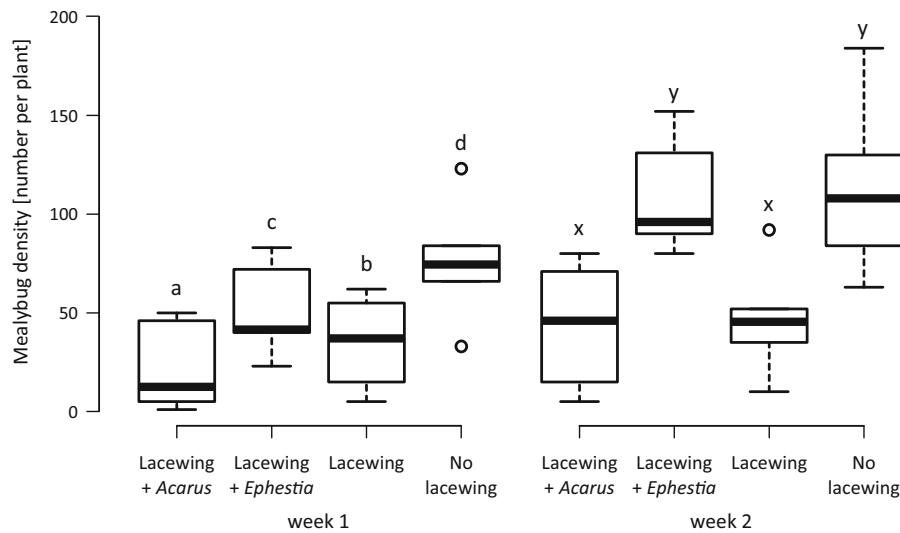
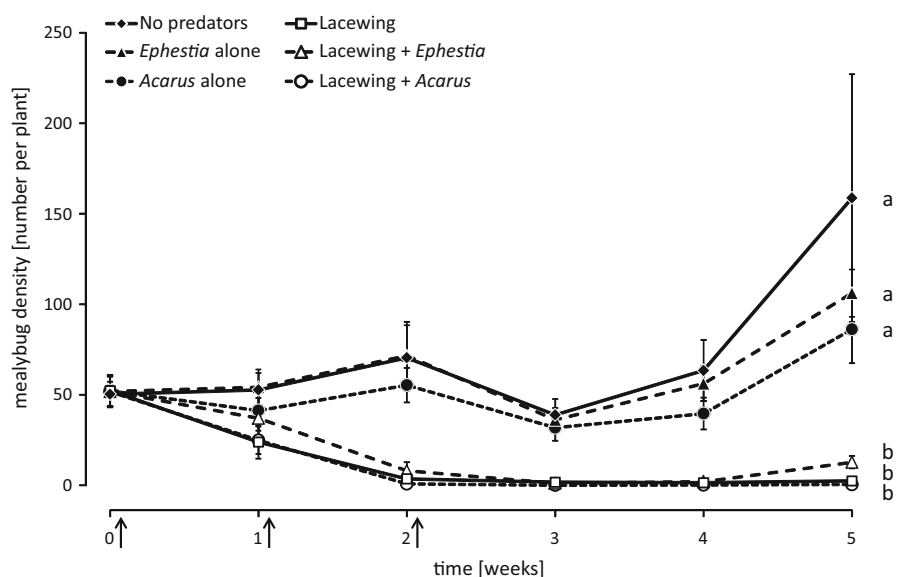


Fig. 4 Population densities of mealybugs on potted rose plants with or without lacewing, *Chrysoperla lucasina*, larvae either alone or combined with sterilized *Ephestia kuehniella* eggs or *Acarus siro*. Shown are the median densities (horizontal line),

the 25 and 75 quartiles (box), and outliers (points). Different letters indicate significant differences among treatments per week (contrasts after GLM, $p < 0.05$)

Fig. 5 Population dynamics of mealybugs on potted rose plants either without predators or with larvae of the lacewing *Chrysoperla lucasina* and with or without additional prey consisting of sterilized *Ephestia kuehniella* eggs or *Acarus siro*. Shown are the mean densities (\pm SE) of mealybugs per plant. The three arrows indicate the timing of predator releases. Different letters next to the curves indicate overall significant differences among treatments (model simplification after LME, $p < 0.05$)



was not observed with multiple releases of lacewing larvae. This is further evidence that the shorter developmental period on a diet of *Ephestia* and mealybugs affects mealybug control, and shows that reduced mealybug predation in the presence of *Ephestia* eggs can be solved by repeated introductions of young lacewing larvae.

Adding low quality prey, such as *Acarus*, had a positive effect on mealybug control, at least in the

short term (Fig. 4). Lacewing larvae were not able to develop well on *Acarus*, but supplementing a diet of mealybugs with mites resulted in a shorter larval developmental time and a higher survival, suggesting that the mites complement a diet of mealybugs. Dean and Schuster (1995) showed that the developmental period of lacewing larvae was shorter on a diet of aphids and whiteflies than on each prey alone, indicating together these prey form a more balanced

diet. Several predators showed higher performance (in terms of developmental time, survival or egg production) on mixed diets than on single-resource diets (Evans et al. 1999; Marques et al. 2015; Messelink et al. 2008; Muñoz-Cárdenas et al. 2014; Oelbermann and Scheu 2002; Toft 2005). Here we found also evidence for the opposite: the survival of lacewing larvae on a diet of mealybugs plus cattail pollen or plus *Artemia* was lower than on a diet of mealybugs alone. It is unclear why the predators continued feeding on *Artemia* cysts or pollen in the presence of mealybugs. Perhaps the predators were unfamiliar with *Artemia* cysts. Hence, they have not been selected to avoid feeding on it. As far as pollen is concerned, we have no clear explanation, except that the pollen and the mealybugs may not occur on the same plant parts, whereas here we offered it together, facilitating simultaneous feeding on it.

Provision of food to predators often results in increased predator densities (Messelink et al. 2014; Wade et al. 2008). However, this is not likely to occur with lacewings in greenhouses because adults probably escape during the migration flights that seem to be required before oviposition (Duelli 1980). Releases of adults in earlier studies also never resulted in new generations (Messelink et al. 2012a), which seems to confirm this hypothesis. Moreover, the adults do not feed on prey (Bozsik 1992). Hence, the control of mealybugs will mainly depend on the released lacewing larvae and their survival. We show here that survival of lacewing larvae was increased in the presence of food of relatively low quality, resulting in better control of mealybugs in the short term (Fig. 4). However, the developmental time was also shortened, which probably caused no increased control after two weeks. Supplying food of high quality strongly reduced the larval period, hence resulted in reduced control.

Commercial formulations of lacewing larvae often contain *Ephestia* eggs and larvae are reared on this food, which might also affect their food preference. Our results suggest that it is better to reduce the quantity of these eggs because they potentially hamper pest control. Field application of other supplemental prey, such as *Acarus*, needs further testing under realistic crop conditions.

We conclude that providing generalist predators with supplemental food may result in increased or decreased pest control, depending on the quality of

supplemental food. Predators may preferentially feed on high quality supplemental food, thus reducing predation on the target pest. Yet, supplying low quality supplemental food is also not advisable because it may be ignored for much the same reason. The best strategy seems to choose a food source that results in better performance of the predators on a mixed diet. Better understanding of the foraging behaviour and the nutritional needs of generalist predators may offer opportunities to enhance their efficacy in biological control.

Acknowledgments This study was funded by the Dutch Product Board for Horticulture. Koppert Biological Systems is thanked for helping with the mass rearing of *C. lucasina*. Biobest N.V. is thanked for providing the sterilized eggs of *E. kuehniella* for the laboratory and greenhouse trials. We are also indebted to De Ruiter Innovations B.V for providing the rose plants. We are grateful to Dr. Charles Henry for confirming the identification of *C. lucasina* based on acoustic analyses of the male songs.

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