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1 **Evaluation of mirid predatory bugs and release strategy for aphid control in sweet pepper**

2 G. J. Messelink¹, C. M. J. Bloemhard¹, H. Hoogerbrugge², J. van Schelt², B. L. Ingegno³ & L.
3 Tavella³

4 ¹ Wageningen UR Greenhouse Horticulture, Bleiswijk, The Netherlands

5 ² Koppert Biological Systems, Berkel en Rodenrijs, The Netherlands

6 ³ Dipartimento di Scienze Agrarie, Forestali e Alimentari (DISAFA), University of Torino
7 Grugliasco, Italy

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12

13 **Correspondence:** Gerben J. Messelink (corresponding author), Wageningen UR Greenhouse
14 Horticulture, PO Box 20, 2265 ZG Bleiswijk, The Netherlands. E-mail: gerben.messelink@wur.nl

15

16

17 **Abstract**

18 Zoophytophagous predators of the family Miridae (Heteroptera), which feed both on plant and prey,
19 often maintain a close relationship with certain host plants. In this study, we aimed to select a
20 suitable mirid predatory bug for aphid control in sweet pepper. Four species were compared:
21 *Macrolophus pygmaeus* (Rambur), *Dicyphus errans* (Wolff), *Dicyphus tamaninii* Wagner and
22 *Deraeocoris pallens* (Reuter). They were assessed on their establishment on sweet pepper plants
23 with and without supplemental food (eggs of the flour moth *Ephestia kuehniella* Zeller and
24 decapsulated cysts of the brine shrimp *Artemia franciscana* Kellogg) and on their effects on aphids
25 with releases before and after aphid infestations. None of the predator species was able to control an
26 established population of aphids on sweet pepper plants; however, the predators *M. pygmaeus* and
27 *D. tamaninii* could successfully reduce aphid populations when released prior to an artificially
28 introduced aphid infestation. The best results were achieved with *M. pygmaeus* in combination with
29 a weekly application of supplemental food. Hence, our results demonstrate that the order and level
30 of plant colonization by mirid predators and aphids determines how successful biological control is.
31 Further studies are needed to evaluate the performance of mirid predatory bugs in sweet pepper
32 crops in commercial greenhouses with multiple pests and natural enemies, in particular to
33 understand how increased variation in food sources affects their feeding behaviour and preferences.

34

35 **Introduction**

36 Zoophytophagous predators of the family Miridae (Heteroptera), which feed both on plant and prey,
37 are increasingly used for pest control in greenhouse vegetable crops either through augmentative or
38 conservation biological control (Castañé et al. 2004; Perdikis et al. 2011; van Lenteren 2012). The
39 most commonly used and commercially mass-produced species are currently *Macrolophus*
40 *pygmaeus* (Rambur) (formerly identified as *Macrolophus caliginosus* Wagner, Castañé et al. 2013)
41 in northern Europe and *Nesidiocoris tenuis* (Reuter) in southern Europe. Typically these predators
42 feed on multiple pest species such as whiteflies (Montserrat et al. 2000), aphids (Alvarado et al.
43 1997), thrips (Riudavets and Castañé 1998), spider mites (Hansen et al. 1999), leaf miners (Arnó et
44 al. 2003) and Lepidoptera species, including *Tuta absoluta* (Urbaneja et al. 2009). Because of their
45 plant-feeding behaviour and oviposition in plant tissue, mirids maintain a close relationship with
46 certain host plants (Perdikis and Lykouressis 2000; Wheeler 2001). Somehow, mirid predators of
47 the tribe Dicyphini (belonging to *Nesidiocoris*, *Dicyphus* or *Macrolophus* genus) seem to be
48 adapted to live on hairy plants (Wheeler 2001; Voigt et al. 2007; Ingegno et al. 2008). Their typical
49 long and slender legs facilitate them, in contrast with many other arthropods, to walk on leaf and
50 stem surfaces with high trichome densities (Voigt et al. 2007). The fact that some hairy plants have
51 glandular trichomes which entrap insects might be one of the reasons why mirids became
52 specialized in hairy plants, as the carrion of entrapped insects provides them with protein-rich food
53 (Krimmel and Pearse 2013).

54 When selecting mirid predatory bugs for pest control, it is important to consider their strong
55 association with certain plant traits, particularly when they are used in a preventive way and their
56 establishment in crops is aimed before pests occur. Such crop ‘inoculation’ strategies with mirid
57 predatory bugs at the start of a cropping cycle are commonly applied in greenhouse tomatoes and
58 eggplants, mainly as a cost-effective method to reach high predator densities (Calvo et al. 2012).
59 Hence, the performance of mirid predatory bugs on plants without pests is an important selection
60 criterion in addition to their efficacy in controlling the target pest species. In this study, we aimed to
61 select a suitable mirid predatory bug for aphid control in sweet pepper. Mirids are so far hardly used
62 in sweet pepper crops, probably because these plants are usually not colonized by naturally
63 occurring mirids, but more commonly by anthocorid bugs (Tavella and Goula 2001; Sanchez et al.
64 2003; Bosco et al. 2008; Ingegno et al. 2011). However, when released in monocultures of sweet
65 pepper, the predator *M. pygmaeus* is able to establish and reproduce in sweet pepper for several
66 months and high densities are able to prevent outbreaks of aphids (Messelink et al. 2011; Messelink
67 and Janssen 2014; Pérez-Hedo and Urbaneja 2014). Yet, it is not clear how effectively *M.*
68 *pygmaeus* controls aphids in sweet pepper and how well it establishes in this crop compared with

69 other species of mirid predatory bugs. Finding other mirid predatory bugs that are even more
70 effective in controlling aphids would be very useful, as aphids are extremely hard to control,
71 particularly in organic sweet pepper cropping systems (Messelink et al. 2011).

72 In this study, we compared *M. pygmaeus* with three other mirid species: *Dicyphus errans* (Wolff),
73 *Dicyphus tamaninii* Wagner and *Deraeocoris pallens* (Reuter), by assessing their establishment on
74 sweet pepper plants and their efficacy as predators of the peach aphid *Myzus persicae* (Sulzer).

75 Laboratory studies show that all these predators can consume large numbers of aphids (Alvarado et
76 al. 1997; Ghavami et al. 1998; Voigt 2005). *Dicyphus errans* is widespread throughout Europe on a
77 wide range of host plants (Ingegno et al. 2008) and observed to colonize tomato crops in northern
78 Italy where it can prey on important pests as *Tuta absoluta* (Meyrick) (Ingegno et al. 2013).

79 *Dicyphus tamaninii* has been tested for pest control in tomato and cucumber crops in Spain, but this
80 species was never recommended because of the observed damage to the tomato fruit (Castañé et al.
81 2011). *Deraeocoris pallens* is considered as a key predator of soft-bodied pests in cotton in the East
82 Mediterranean region (Ghavami et al. 1998), but the predator was also observed on several other
83 host plants (Atakan and Tunç 2010) and was able to reduce whitefly populations on eggplant
84 (Ulubilir et al. 1997). However, the performance of *D. errans*, *D. tamaninii* and *D. pallens* on sweet
85 pepper is unknown. Sweet pepper plants have smooth and waxy leaf surfaces with trichomes
86 clustered in domatia only on the abaxial side of the leaves (Ferreira et al. 2008), and this lack of
87 trichomes could be a disadvantage for hairy plant associated bugs like Dicyphini. However, even if
88 sweet pepper is not the preferred host plant because of these morphological traits, the predators may
89 still establish in this crop when no alternative plant species are present, as has been observed for *M.*
90 *pygmaeus* (Messelink and Janssen 2014). Moreover, the lack of trichomes might be compensated by
91 the pollen and nectar provided by the continuously flowering sweet pepper plants (Portillo et al.
92 2012). Establishment might also be enhanced by supplemental food (Messelink et al. 2014). Hence,
93 we additionally evaluated the population increase of predatory bugs on flowering sweet pepper
94 plants provided with weekly food supplements of eggs of the flour moth *Ephesia kuehniella* Zeller
95 and decapsulated cysts of the brine shrimp *Artemia franciscana* Kellogg, which are both suitable
96 food sources for generalist predatory bugs (Arijs and De Clercq 2001; De Clercq et al. 2014).

97 Effects on aphids were evaluated with predator releases both before and after establishment of
98 aphids. As mirid predatory bugs have a relatively long generation time and mix their diet with prey
99 and plant feeding (Gillespie and McGregor 2000), we hypothesized that high initial predator–pest
100 ratios are needed to achieve a sufficient control of aphids. This might be obtained through prior to
101 pest releases of mirids combined with supplemental food to increase predator densities. The results

102 of this study may help to develop practical guidelines for enhancing aphid control with generalist
103 predators in commercial sweet pepper crops.

104

105 **Materials and Methods**

106 Plants and insects

107 The origin of the four selected predatory bugs is presented in table 1. Collected predatory bugs were
108 maintained as laboratory rearings on bean pods (*Phaseolus vulgaris* L.) and eggs (killed by
109 freezing) of the flour moth *E. kuehniella* as food, following the methods described by Van den
110 Meiracker and Ramakers (1991) for rearing anthocorid bugs. The culture of *D. pallens* was
111 additionally provided with sweet pepper leaves infested by *M. persicae*, as this prey enhanced the
112 reproduction rate. Tobacco leaves (*Nicotiana tabacum* L.) were added to the culture of *D. errans* to
113 enhance oviposition. Sweet pepper plants (*Capsicum annuum* L.), cv Spider (Enza Zaden), were
114 grown in peat by a commercial plant propagator without application of pesticides. Peach aphids (*M.*
115 *persicae*) of the red phenotype were reared on sweet pepper plants of the same cultivar in a separate
116 greenhouse compartment.

117 Greenhouse experiment with predator releases after aphid establishment

118 Aphid control with releases of mirid predatory bugs after establishment of aphids was evaluated in
119 16 walk-in cages of 1*2*2 m made of fine insect gauze (mesh size 0.22 9 0.31 mm), which were
120 placed in a greenhouse compartment of 144 m² at the Institute of Wageningen UR Greenhouse
121 Horticulture. The experiment had a completely randomized design with four replicates of the
122 following treatments: (i) no predators (only *M. persicae*), (ii) *M. pygmaeus* (iii) *D. errans* and (iv)
123 *D. pallens*. *Dicyphus tamaninii* was not included in this experiment, because of the limited available
124 numbers when starting the trials. Each cage was provided with four potted sweet pepper plants, cv
125 Spider, which were planted in peat in 10 l pots. The plants were grown according to a three-stems-
126 per-plant system, resulting in 12 sweet pepper stems per cage. Plants were provided with a standard
127 nutrient solution through drip irrigation. The plants were infested in September with aphids when
128 the crop was about 1 m high at densities of 20 aphids of mixed age per plant, thus 80 aphids per
129 cage. This resulted after 2 weeks in an average density of 1325 (SE 67) aphids per cage. Predators
130 were released 1 day after this assessment of aphid establishment. Each cage was provided with 40
131 one-week-old adults (20 males and 20 females) and 40 third instar nymphs. Thus the average
132 predator: aphid ratio at the start of this experiment was 1 : 16.5. Densities of aphids and mirid
133 predatory bugs were assessed weekly during four consecutive weeks by counting the total number
134 of aphids and predators on 24 randomly selected leaves per cage: 12 leaves in the upper part of the
135 plants and 12 leaves in the lower part. All observations on the plants were non-destructively

136 performed inside the cages between 8:00 and 12:00 AM. Temperature and relative humidity were
137 registered every 5 min throughout the experiment with a climate recorder (Hoogendoorn Growth
138 Management) inside one of the cages. The experiment was conducted in September– October, and
139 during that period, the average measured temperature and relative humidity in the cages were
140 20.7°C (range 17.5–27°C) and 75% (range 42–90%), respectively.

141 Greenhouse experiment with predator releases prior to aphid releases

142 A second greenhouse experiment was set-up similar to the first one, but with releases of predatory
143 bugs prior to aphid releases. The establishment of the predators on flowering sweet pepper plants
144 was compared with the establishment on plants that received a weekly supply of additional food
145 consisting of 0.6 g eggs of *E. kuehniella* (killed by freezing) and 0.3 g freeze dried decapsulated
146 cysts of *A. franciscana* per cage, both obtained from Koppert Biological systems (non-commercial
147 R&D materials). This food was added weekly by manually sprinkling it equally distributed over the
148 leaves. The following eight treatments were tested in four replicates: (i) no predators, (ii) *M.*
149 *pygmaeus*, (iii) *D. errans*, (iv) *D. pallens* (v) *M. pygmaeus* + food, (vi) *D. errans* + food, (vii) *D.*
150 *pallens* + food and (viii) *D. tamaninii* + food. Plants were inoculated with predatory bugs by twice
151 releasing 16 one-week-old adults (eight females and eight males) per cage. The second introduction
152 was 2 weeks after the first, to establish populations of mixed developmental stages. Aphids were
153 introduced 5, 6 and 7 weeks (week number 18, 19 and 20 respectively) after the last predator
154 releases, each time 120 aphids of mixed age were released per cage (30 aphids per plant). Densities
155 of aphids and predators were followed in the same way as in the first experiment. In addition, 10
156 fresh flowers per cage were randomly selected to count the number of mirid predators in the
157 flowers. The experiment was conducted in March–May, and during that period, the average
158 measured temperature and relative humidity in the cages were 22.3°C (range 15.2– 31.8°C) and
159 71% (range 32 – 88%), respectively. Data were analysed with the same methods as for the first
160 greenhouse experiment.

161 Predation rates in the laboratory

162 In addition to the greenhouse experiments, we measured predation rates of the two best performing
163 predatory bugs. From each selected species 20 one-week old females were individually starved for
164 24 h in a glass vial with only some water-soaked cotton, to ensure they were motivated to feed. The
165 experiment was conducted in plastic boxes (Ø 6 9 5 cm) with a sweet pepper leaf disc that was
166 embedded upside down in water agar (1% agar), making the abaxial side of the discs available to
167 the aphids and predators. Ventilation was possible through a hole in the lid covered with insect
168 gauze (mesh size 80 µm). Each box was provided with 40 first instar nymphs of *M. persicae*, which
169 were directly isolated from the greenhouse colony with a small brush. Preliminary experiments

170 showed that 40 nymphs are ample prey for one female predator per day. After adding the aphids,
171 each box was provided with one of the starved females. All 40 boxes were placed upside down
172 (natural position of aphids) in a climate room under 16 h of artificial illumination per day, at 25°C
173 and 70% RH. Predation of nymphs by the adult predators, recognized by the presence of bodies that
174 were sucked partly or completely empty, was assessed after 24 h.

175 Statistical analyses

176 Population dynamics of aphids and predators in the two greenhouse trials were analysed with
177 repeated measures ANOVA, and differences among treatments were tested with Fisher's least
178 significance difference (LSD) test ($P < 0.05$). In addition, it was analysed whether the application of
179 food (only for *M. pygmaeus*) or the presence of aphids caused a shift in the fraction of predators
180 occupying the flowers. A two-way ANOVA was performed with arcsine square root transformed
181 average fractions of predators in the flowers (densities in 10 flowers/densities on 24 leaves) with
182 treatment and the presence of aphids (week 4–8 vs. week 9–14) as factors. Differences among
183 treatments were tested with Fisher's LSD test ($P < 0.05$). Predation rates of the laboratory trial were
184 analysed using a generalized linear model (GLM) with a Poisson distribution of the data. All
185 statistical analyses were performed using the statistical package Gen-Stat Release 16.1 (Payne et al.
186 2010).

187

188 **Results**

189 Greenhouse experiment with predator releases after aphid establishment

190 Aphid densities increased strongly in all treatments (fig. 1a), and none of the predator species was
191 able to significantly reduce the increase of aphids ($F_{3,9} = 3.17$, $P = 0.24$). Densities of predators
192 were significantly different among treatments ($F_{2,6} = 5.2$, $P = 0.049$), with the highest densities
193 observed for *M. pygmaeus* and the lowest for *D. pallens* (fig. 1b).

194 Greenhouse experiment with predator releases prior to aphid releases

195 The predators *D. errans* and *D. pallens* were not able to establish a population in the sweet pepper
196 plants without application of food. *Deraeocoris pallens* was not observed anymore from 4 weeks
197 after the second release of predators and only a few adults of *D. errans* remained alive during the
198 trial, without producing a new generation. These treatments were therefore excluded from further
199 analyses. The population dynamics of aphids were significantly different among the remaining
200 treatments ($F_{5,18} = 42.33$, $P < 0.01$). The best control of aphids was achieved in the treatment of *M.*
201 *pygmaeus* combined with the weekly food application, followed by *D. tamaninii* + food and *M.*
202 *pygmaeus* without food (fig. 2). The predator + food treatments of *D. errans* and *D. pallens* were
203 not able to prevent a strong increase of aphids (fig. 2). Densities of predators were significantly

204 different among treatments both on the leaves ($F_{4,15} = 83.45$, $P < 0.01$) and in the flowers ($F_{4,15} =$
205 280.48 , $P < 0.01$). The highest predator densities were achieved in the treatments with food
206 application for the species *M. pygmaeus* and *D. tamaninii* (fig. 3). The weekly application of food
207 was beneficial for the predator *M. pygmaeus*; aphid densities were significantly lower and predator
208 densities significantly higher when food was added compared to the treatment without food (figs 2
209 and 3). The fractions of predators in the flowers were significantly different among predator
210 treatments ($F_{4,30} = 22.04$, $P < 0.01$) and also affected by the releases of aphids ($F_{1,30} = 10.99$, $P =$
211 0.003) (fig. 4). Weekly food supplements significantly reduced the fraction of *M. pygmaeus*
212 predators in the flowers compared to the treatment without food application (fig. 4). A strong shift
213 was observed for the predator *D. errans* from the flowers to the leaves when aphids were present on
214 the plants, whereas such a shift did not occur with the other predators species (fig. 4).

215 Predation rates in the laboratory

216 The daily predation rates of first instar aphids by females of the two best performing predatory bugs
217 *M. pygmaeus* and *D. tamaninii* were on average 21.7 (\pm SE 2.7) and 22.8 (\pm SE 2.0) individuals,
218 respectively. These rates were not significantly different ($F_{1,37} = 1.03$, $P = 0.317$).

219

220 **Discussion**

221 The results of this study demonstrate that the order and level of plant colonization by the predator
222 and pest determines how successful biological control with generalist predators is. None of the
223 predator species was able to control an established population of aphids, even at the relatively high
224 predator: prey ratio of 1 : 16.5. The predation rate experiment in the laboratory showed that female
225 predators can consume about 20 young aphids/day, which might potentially have been enough to
226 consume all young aphids on the plants within a few days. One of the possible reasons for this gap
227 between the laboratory and field might be that the predation rates are reduced by the presence of
228 alternative food sources provided by the plant (pollen and nectar). Another laboratory study with *M.*
229 *pygmaeus* showed such effects: consumption rates of aphids were reduced with 44% when flowers
230 of sweet pepper were added to sweet pepper leaves (Lykouressis et al. 2014). In our study, it was
231 also observed that the predators feed on the secreted honeydew of the aphids, which could
232 additionally distract them from feeding on the aphids themselves. Furthermore, the age structure of
233 the predator and aphid populations could have affected predation rates. Also, the released male
234 predators and third instar nymphs probably had lower predation rates than the female predators,
235 which were assessed in the laboratory. Our results are in contrast with the study of Pérez-Hedo and
236 Urbaneja (2014), which showed a good control of aphids when mirid bugs were released after

237 infestation of aphids. However, the predator–prey ratios are not clear in this study and also the
238 provision of alternative food was prevented by removing the flowers.

239 Much better results were achieved in our study in the second experiment with preventive releases of
240 predators. Both the predators *M. pygmaeus* and *D. tamaninii* strongly reduced the increase of aphids
241 compared to the plants without predators. The best results were achieved with *M. pygmaeus* in
242 combination with a weekly application of supplemental food. This additional food increased the
243 population of predators to very high densities which favoured the control of aphids. These results
244 suggest that a high predator: prey ratio is needed to achieve sufficient control. Aphids multiply
245 extremely fast by viviparous parthenogenetic reproduction, resulting in relative growth rates on
246 sweet pepper of 0.36 females per female per day (Dewhurst et al. 2012). Aphids will soon
247 outnumber mirid predatory bugs which have a relatively low reproduction rate: for example
248 0.0615–0.0958 females per female per day for *M. pygmaeus* on aphids (Margaritopoulos et al. 2003;
249 Perdikis and Lykouressis 2004). Thus, the numerical response of the predators is by far not fast
250 enough to control aphids. Preventive releases of predators can solve this problem, as this prior to
251 pest establishment can result in relatively high initial predator: pest ratios which are enough to
252 control the aphids. Moreover, predators might aggregate in patches of aphids in the field.

253 Olfactometric studies showed that mirids strongly respond to odours of plants infested by pests
254 (Ingegno et al. 2011, 2013; Pérez-Hedo and Urbaneja 2014). This suggests that the predators can
255 have an aggregative numerical response, also referred to as short-term apparent competition (Holt
256 and Kotler 1987). Such aggregation was also suggested by our study, because a much lower fraction
257 of *M. pygmaeus* was found in the flowers when food was added to the leaves. Our results also
258 showed that *D. errans* seems to shift from flowers to leaves when aphids were added. This shift was
259 not observed for *M. pygmaeus* and *D. tamaninii*, as their fraction of predators in the flowers
260 remained similar on plants with or without aphids. However, these two predatory bugs controlled
261 aphids much better than the other predator species, thus a part of the predator population may have
262 gone back to the flowers when most aphids were consumed.

263 The predators *D. errans* and *D. pallens* were not able to establish in flowering sweet pepper plants
264 without supplemental food. The nectar and pollen provided by the flowers are apparently not
265 suitable for adult reproduction or to complete the development of these predators. The presence of
266 *D. errans* in the flowers suggests that they do consume the pollen and nectar, but these food sources
267 might lack essential nutrients for the juvenile development. *Deraeocoris pallens* was only found
268 occasionally in the flowers of sweet pepper, indicating the unsuitability of sweet pepper pollen for
269 this predator. This species might, more than the other tested mirids, need living prey for its
270 development. Even the supplemental food of *Ephestia* eggs and *Artemia* cysts did not result in a

271 successful establishment of this predator species. The first generation offspring of released adults of
272 *D. pallens* was not able to complete development and died out slowly.

273 The reason why *M. pygmaeus* and *D. tamaninii* were more successful in establishing a population
274 on sweet pepper than the other predators remains unclear. Field surveys indicate that sweet pepper
275 is not a preferred host plant, as pepper plants are only occasionally colonized by these predators
276 (Tavella and Goula 2001; Sanchez et al. 2003). However, these predators might be better adapted to
277 feed on pollen and nectar than the other tested mirids (Vandekerkhove and De Clercq 2010). Their
278 ability to reproduce on food provided by the plant is a major advantage for establishing and
279 augmenting predator populations in sweet pepper prior to pest infestations, which makes them
280 suitable candidates for ‘seasonal inoculative’ biological control (van Lenteren and Woets 1988).

281 Biological control of aphids is, so far, usually based on releases of specialist natural enemies such
282 as parasitoids (mainly Aphididae), or the predatory midge *Aphidoletes aphidimyza* (Rondani)
283 (Blümel 2004). However, preventive releases of generalist predators such as *Orius majusculus*
284 (Reuter) or *M. pygmaeus* can, in addition to these natural enemies, enhance aphid control
285 (Messelink et al. 2013; Messelink and Janssen 2014). This will probably also result in lower costs,
286 as inoculative releases of generalist predators may reduce the need for repeated releases of
287 expensive specialist aphid natural enemies. The results of this study confirm that releases of *M.*
288 *pygmaeus* in flowering sweet pepper plants before pest arrival can be a successful strategy to
289 prevent outbreaks of aphids. A possible drawback is the intraguild predation by these generalist
290 predators on specialist aphid predators, such as larvae of the predatory midge *A. aphidimyza* or
291 syrphids (Fréchette et al. 2007; Messelink et al. 2013). However, the strong contribution of
292 generalist predators to the control of aphids may outweigh the negative effects of intraguild
293 predation (Messelink et al. 2013). An additional benefit of using generalist predatory bugs is their
294 contribution to the control of other pests in sweet pepper such as caterpillars, spider mites or
295 whiteflies (Hansen et al. 1999; Montserrat et al. 2000). Hence, biological control of aphids could be
296 enhanced with prior to pest releases of *M. pygmaeus* or *D. tamaninii* combined with application of
297 supplemental food for ‘boosting’ their densities. However, their performance in sweet pepper crops
298 with multiple pests and natural enemies needs to be further evaluated, in particular how increased
299 variation in food sources affects their feeding behaviour and preferences.

300

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307

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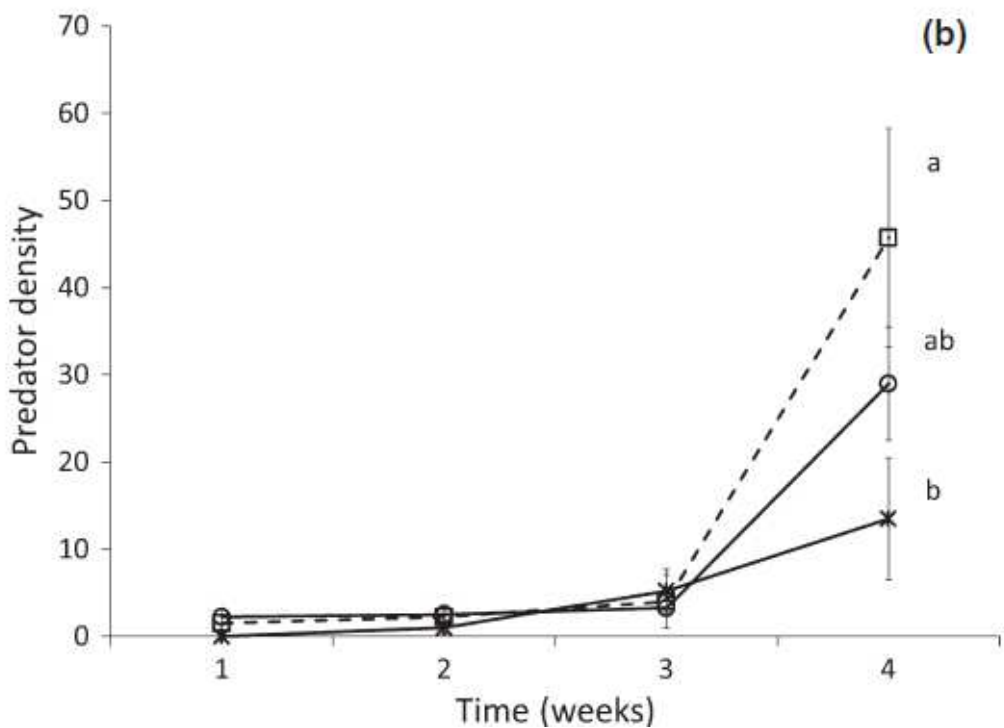
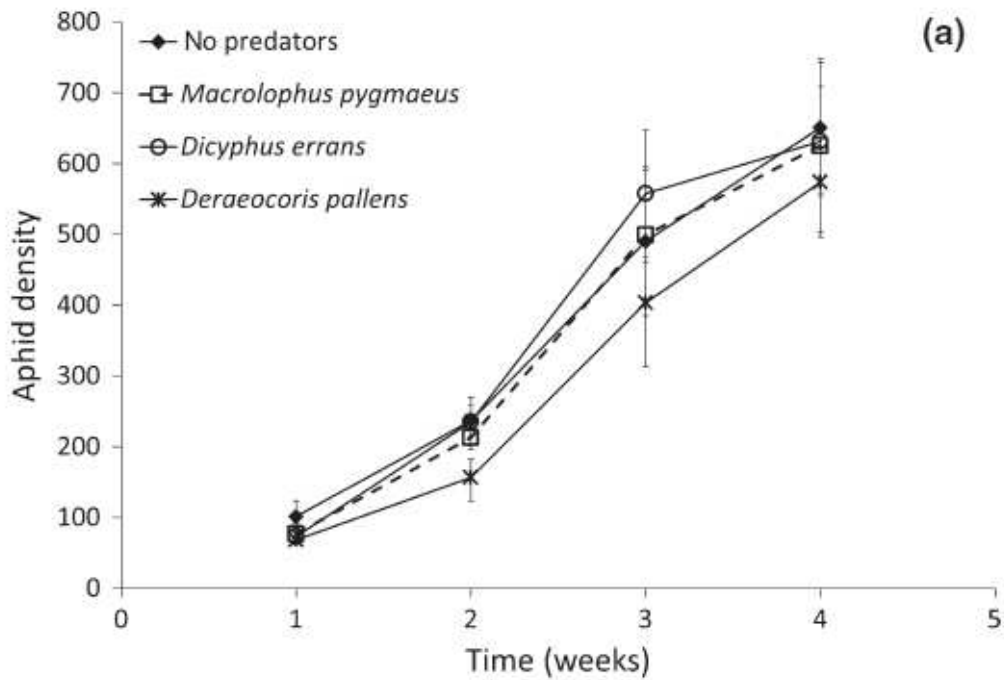
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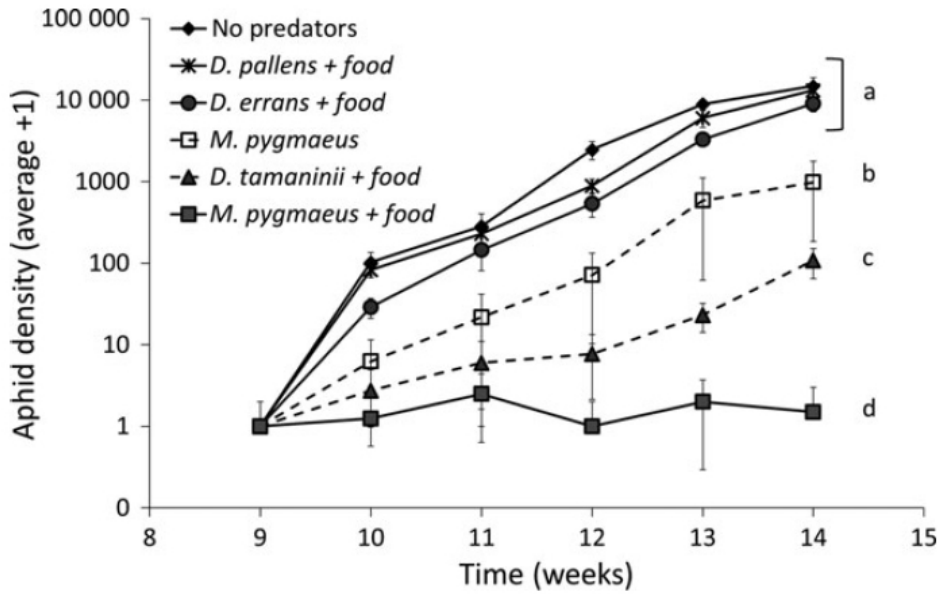
423

424 **Figure 1.** Population increase of the peach aphid *M. persicae* (A) and its predators (B) on sweet

425 pepper plants. Aphids were released 3 weeks and predators 1 week before the first assessment.

426 Average (\pm SE) densities per 24 leaves through time are shown. Different letters indicate significant

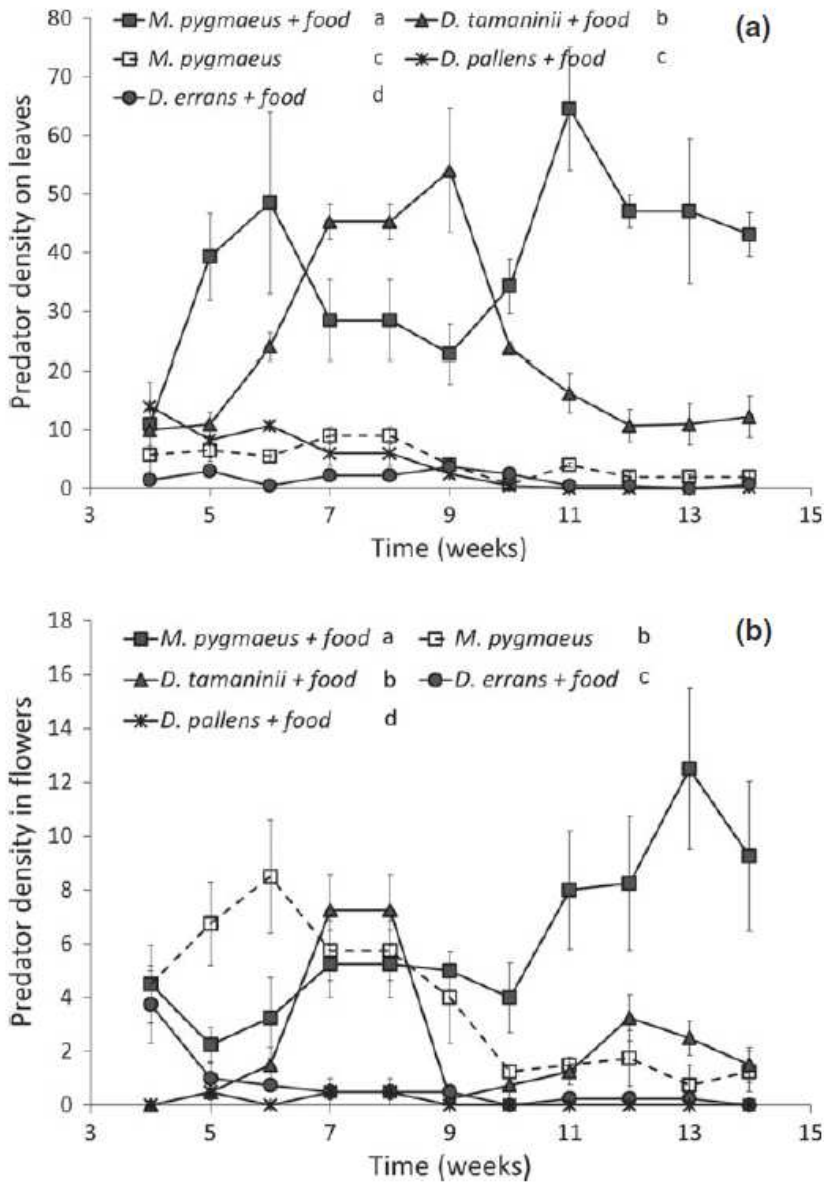
427 differences among treatments through time (Fisher's LSD test, $P < 0.05$).



428

429 **Figure 2.** Population dynamics of the peach aphid *M. persicae* on sweet pepper plants inoculated
 430 with different species of predatory bugs with or without supplemental food (*Ephestia* eggs and
 431 *Artemia* cysts) compared with plants without predators. Predators were released in week 1 and 3
 432 and aphids in week 8, 9 and 10. Shown are average (\pm SE) densities + 1 of aphids per 24 leaves
 433 through time. Different letters indicate significant differences among treatments through time
 434 (Fisher's LSD test, $P < 0.05$).

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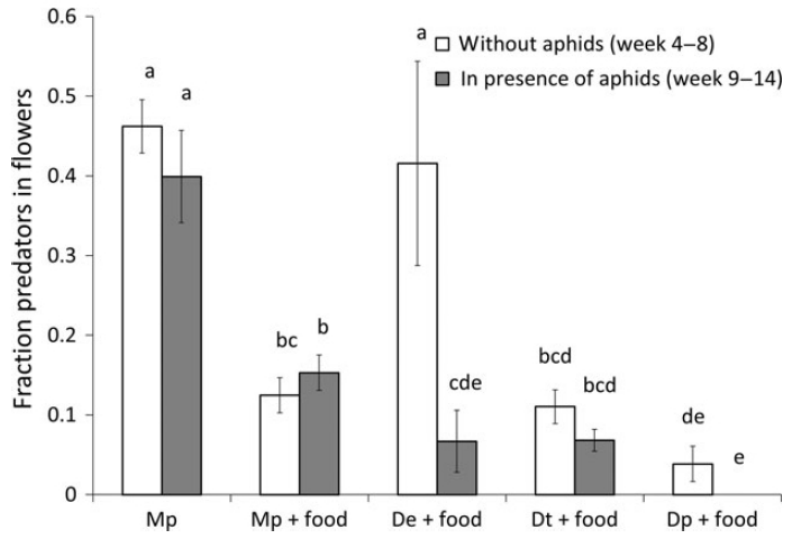


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438 **Figure 3.** Population dynamics of mirid predatory bugs on sweet pepper plants. Four treatments
 439 were provided weekly with supplemental food (*Ephestia* eggs and *Artemia* cysts). Predators were
 440 released in week 1 and 3 and aphids in week 8, 9 and 10. Shown are average (\pm SE) densities per 24
 441 leaves (a) or per 10 flowers (b) through time. Different letters indicate significant differences
 442 among treatments through time (Fisher's LSD test, $P < 0.05$).

443



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445

446 **Figure 4.** Relative abundance of mirid predatory bugs in the flowers of sweet pepper plants in
 447 presence or absence of aphids and with or without additional food (*Ephestia* eggs and *Artemia*
 448 cysts). Shown are average (\pm SE) fractions of predators in the flowers, Mp = *Macrolophus*
 449 *pygmaeus*, De = *Dicyphus errans*, Dt = *Dicyphus tamaninii* and Dp = *Deraeocoris pallens*.
 450 Different letters indicate significant differences among treatments (Fisher's LSD test, $P < 0.05$).

451

452

453 **Table 1.** Origin and production method of selected predator species.

Predator species	Host plant from which collected	Year and area of collection
<i>Macrolophus pygmaeus</i> (Rambur)	<i>Solanum lycopersicum</i> (L.)	1994, southern France
<i>Dicyphus errans</i> (Wolff)	<i>Geranium</i> sp.	2012, Northern Italy
<i>Dicyphus tamaninii</i> Wagner	<i>Solanum luteum</i> Mill.	2012, Northern Spain
<i>Deraeocoris pallens</i> (Reuter)	<i>Inula viscosa</i> (L.)	2011, Southern Turkey

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