Importance of feeding behaviour on life cycle in the zoophytophagous bug *Dicyphus geniculatus*

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Abstract

Dicyphus geniculatus (Fieber) (Heteroptera Miridae) is a Mediterranean mirid that has been observed in public green areas in towns of eastern and western provinces of Spain feeding on whiteflies and thrips on *Dianthus caryophyllus* L. carnations. In this article, the relative importance of feeding behaviour with respect to the duration of nymphal development and nymphal survival, as well as reproduction, was investigated. Nymphs of *Bemisia tabaci* (Gennadius), larvae of *Frankliniella occidentalis* (Pergande) and carnation plants introduced into a 50 × 50 × 50 cm methacrylate box, together with adults mirids, in a climate-controlled chamber (25 ± 1 °C, 60 ± 5% HR, 16:8 h L:D photoperiod) were used to analyse feeding behaviour. In particular, data on realised fecundity, sex ratio and adult longevity were analysed. Realised fecundity differed significantly with respect to prey availability ($F_{1, 267}$ = 44504.92; p ≤ 0.001). The sex ratio did not differ from 1(♂♂):2(♀♀+♂♂) with respect to feeding regimes ["with *B. tabaci* prey" (37/53+37 = 0.41), χ^2 = 1.434, df 1, p = 0.231, "with *F. occidentalis* prey" (42/50+42 = 0.46), χ^2 = 0.200, df 1, p = 0.655] or prey type (*B. tabaci* or *F. occidentalis*, χ^2 = 0.564, df 1, p = 0.453). Adult longevity differed significantly in terms of prey availability ($F_{2, 534}$ = 58.89, p ≤ 0.001) and longevity differed for each sex within each feeding regime ($F_{1, 534}$ = 14.13; p ≤ 0.001). *D. geniculatus* can survive on a host plant diet exclusively but could not complete its development in the absence of supplemental prey food, indicating that *D. geniculatus* requires an animal component in its diet. Other zoophytophagous dicyphines are successfully used as beneficials in integrated pest management in horticultural crops. Thus, *D. geniculatus* has a potential role in the biological control of carnation pests, and therefore may be a promising pest biological control agent, thus contributing to urban area sustainability.

Key words: *Dicyphus geniculatus*, Miridae, Caryophyllaceae, zoophytophagy, biological control, urban green areas.

Introduction

Although mirid bugs (Heteroptera Miridae) have been traditionally considered as phytophagous and include several agricultural pests, many of them also eat prey and are known to be zoophytophagous (Wheeler, 2000a). Because of this partly predatorial feeding behaviour, there is currently increasing recognition of their potential for use in pest biological control (Albajes and Alomar, 1999; Alomar, 2002; Lucas and Alomar, 2002; Wheeler, 2000b; Urbaneja-Bernat *et al*., 2013; Maselou *et al*., 2014; Pérez Hedo *et al*., 2015). Nevertheless, in order to maximise benefits and to minimise plant injury, it is necessary to obtain information about the relative influence that the host plant and prey availability have on the biology of the zoophytophagous species (Urbaneja *et al*., 2005), and thus the ultimate utility of these facultative predators in the biological control of pests (Wheeler, 2001).

Several mirid Dicyphine zoophytophagous species have been collected among open-field and/or protected horticultural and ornamental crops in the Mediterranean Basin: *Macrolophus pygmaeus* (Rambur), *Nesidiocoris tenuis* (Reuter), *Dicyphus errans* (Wolff), *Dicyphus tamaninii* Wagner (Albajes and Alomar, 1999; Wheeler, 2001), *Dicyphus hyalinipennis* (Burmeister) (Ceglarska, 1999), *Dicyphus cerastii* Wagner (Carvalho and Mexia, 2000) and *Dicyphus maroccanus* Wagner (Abbas *et al*., 2014). These species have been implicated in the biological control of several pests, such as whiteflies,

aphids, thrips, leafminers, spider mites (Malausa *et al*., 1987; Malausa, 1989; Arzone *et al*., 1990; Alomar *et al*., 1991; Calabrò and Nucifora, 1993) and the more recently introduced South American tomato pinworm *Tuta absoluta* (Meyrick) (Urbaneja *et al*., 2009; Ingegno *et al*., 2013). These pests are frequently found on both horticultural and ornamental crops, where they have a very high economic impact. However, most of the research and subsequent implementation has been undertaken on horticultural crops, and much less attention has been devoted to the potential use of dicyphine zoophytophagous mirid species with ornamental crops, mainly due to the very low damage thresholds in these crops (Enkergaard and Brødsgaard, 2006) when aiming to achieve a high-quality product (Gullino and Wardlow, 1999; Marsh and Gallardo, 2009). Emerging research is being developed at present in Europe to explore possible control of whiteflies among greenhouse ornamental crops by *M. pygmaeus*, *D. errans*, *Dicyphus eckerleini* Wagner, *D. maroccanus* and *D. tamaninii*. Examples of successful IPM in ornamentals may be found in Gullino and Wardlow (1999) and Murphy *et al*. (2011).

Dicyphus geniculatus (Fieber) is widespread in Europe, and its presence is also signalled in Turkey and Azerbaijan (Kerzhner and Josifov, 1999). Compared to other *Dicyphus* species, little information is known about *D. geniculatus* biology. Wagner and Weber (1964) name *Salvia glutinosa* L. (Lamiaceae) and *Silene baccifera* L. (Caryophyllaceae) as host plants. Éhanno (1987) reports observations of the species in grasslands

in France, and *S. baccifera*. *D. geniculatus* has been reported in northern Italy in horticultural areas in Piedmont and Liguria regions, on *Mentha* sp. (Lamiaceae), *Parietaria officinalis* L. (Urticaceae) and *Silene* spp. (Tavella and Goula, 2001), as well as on *S. glutinosa* and *Digitalis grandiflorum* Miller (Plantaginaceae) in the Piedmont Alpine valley (Ingegno *et al*., 2008). As it occurs with other dicyphines, a mirid subtribe including species that specialise in sticky plants (Wheeler, 2001; Wheeler and Krimmel, 2015), most *D. geniculatus* host plant species are provided with trichomes, either glandular or not; among vascular plants, 30% are sticky or hairy (Duke, 1994). This latter group includes conspicuous crops such as cotton, tomato and tobacco. The effects of plant trichomes on predator efficacy have been tested in many studies, and a good synthesis may be found in Riddick and Simmons (2014a). Most studies have shown that plant hairiness is detrimental to most predatory insects; others have demonstrated a neutral effect. A certain number of predatory insects adapt (Riddick and Simmons, 2014b). Plant trichomes make herbivore locomotion more difficult and entrap pollen as well as insects (either tourist or not), providing a diversity of leaf surface resources (phylloplane) to insects that specialise in hairy plants (Krimmel, 2014). Entangled insects transform into carrion, which is attractive to dicyphine predators (Wheeler, 2001) in an interaction that is not very different from the mirid-spider interaction (Wheeler and Krimmel, 2015). Stickiness may therefore be interpreted as an indirect plant defence (Krimmel and Pearse, 2013).

In the present work, *D. geniculatus* was observed on carnations (*Dianthus caryophyllus* L.), which have leaves that are hairless and waxy, thus contrasting with most trichogenous host plants inhabited by dicyphines. Voigt and Gorb (2010) hypothesise that dicyphine locomotion on hairy plant surfaces may be carried out according to two different strategies: either avoiding or overcoming stickiness and/or tricome toxicity. *Dicyphus* spp. are light insects that use plant trichomes as useful clinging structures, to keep their slim bodies separated from the hairy plant surface by means of their relatively long legs, and get rid of sticky tricome compound by grooming frequently. However, a specialisation in hairy plants does not preclude locomotion on smoother surfaces, even glass (Voigt and Gorb, 2010), which is possible due to the presence of special dentate claws and large pad-like pseudopulvilli, characteristic of most Bryocorinae (Cassis and Schuh, 2012). Surveys on sweet pepper, a plant with very smooth, hairless surfaces, reported the presence of *D. errans* and *D. tamaninii* in Spain (Goula and Alomar, 1994) and Italy (Tavella and Goula, 2001), *M. pygmaeus* in Greece (Perdikis and Lykouressis, 2004) and the Netherlands (Messelink *et al*., 2011) and, together with *N. tenuis* and *D. maroccanus*, in Spain (Jacas *et al*., 2008; Pérez-Hedo and Urbaneja, 2014). Protected crops of glabrous ornamental *Euphorbia milii* Des Moulins (Euphorbiaceae) and *Serissa foetida* (L.f.) Lam. (Rubiaceae) were successfully colonised by *D. tamaninii* as part of research on mirid predation on *Frankliniella occidentalis* (Pergande) (Blaeser *et al*., 2004). Under natural conditions,

D. geniculatus has been recorded among the *Digitalis grandiflorum* Miller (Ingegno *et al*., 2008) glabrous upside and sparsely pubescent underside (Tutin *et al*., 1972). Thus, several examples of dicyphine that do not colonise hairy host plants may be found. In this context, *D. geniculatus* living on *Dianthus caryophyllus* should not be surprising.

D. caryophyllus has been appreciated as ornamental since ancient times, and it is the wild species from which most commercial ornamental carnations have been derived (Chacón *et al*., 2013). Aside from its use as a cut flower and flower pot plant, *D. caryophyllus* has a long and strong reputation for medical use in the Far East (Chandra *et al*., 2016). Carnation cropping is largely implemented. For example, in 2013 in Spain, more than 40% of flower crop surfaces were devoted to growing carnations; exports of the crop increased nearly 70% in 2013 (COAG, 2014). Unfortunately, production is frequently at risk due to diseases and pests. In Spain, main carnation crop pests are thrips, mainly *F. occidentalis*; aphids, mainly *Myzus persicae* Sulzer; leafminers, *Liriomyza dianthicola* (Venturi); caterpillars, *Cacoecimorpha pronubana* (Hubner) and *Epichoristodes acerbella* (Walker) (Belda and Moerman, 2008; INFOAGRO, 2016). The presence of mites, spider mites, scales, leaf miners and cutworms has also been reported and some require quarantine (Trujillo *et al*., 1989; Australian Government, 2006). As is the rule for ornamentals (Gullino and Wardlow, 1999), carnation crop pest management usually relies on pesticides, although preventive measures such as the sanitation of crop areas and seed certification or monitoring, together with IPM, are increasing (Belda and Moerman, 2008), with the aim of reducing the environmental pollution and pesticide exposure experienced by growers, labourers and applicators, among others (Marsh and Gallardo, 2009).

For several years, *D. geniculatus* has been observed in several towns of the Alicante, Valencia and Salamanca provinces (Spain), feeding on whiteflies and thrips on carnations (*D. caryophyllus*) in urban public green areas, causing no apparent significant damage to the host plant (author's personal observations). Plants with no preying pests were not colonised by *D. geniculatus*. Urban sustainability is a topic that continues to garner significant attention, as may be concluded from the large revision by Kabisch *et al*. (2015). Thus, pest management in urban green areas should not be considered an additional challenge neither for those concerned with the environment or with citizen and pet health in urban areas that are already polluted. Urban green areas provide important ecological services and social benefits (Coley *et al*., 1997; Haase *et al*., 2014), and ornamental plants are perceived by citizens as "decorative" (Kravanja, 2006). In particular, carnations in Spain are largely prized for their brilliant, colourful flowers. Thus, managers have to successfully implement the most conservative and gentle strategies, *i.e*., IPM, to control pests in urban green areas in order to achieve plants of the highest quality with superior aesthetics: intrinsic values of ornamental plants (Marsh and Gallardo, 2009). According to observations on other beneficial congenic species, *D. geniculatus* may significantly contribute to

control whiteflies and thrips on carnations, among both greenhouse and open-field crops, as well as in urban green areas. In this article, the influence of prey availability on the life cycle (nymphal stage survival and development) and on certain reproductive parameters (realised fecundity, sex ratio and adult longevity) of this mirid species have been evaluated.

Materials and methods

Plants

Pesticide-free carnation garden plants (25 cm high), *Dianthus caryophyllus* L. (var. Standard) (Viveros Devís, Valencia, Spain), were used in all assays. Carnation seedlings were transplanted to $10 \times 10 \times 10$ cm pots using a substrate composed of peat and perlite as the growing medium and maintained until use under the following environmental conditions: 14-24 °C, 60-70% RH and 12:12 h L:D.

Insects

D. geniculatus individuals came from populations originally collected on carnation plants from several public and private gardens in the province of Alicante (V-IX-2006/08). Goula, according to Wagner (1974), identified individuals based on external morphological characteristics and biometrics and an examination of male genitalia. Specimens were maintained at the Fundación Entomológica Torres-Sala (Valencia) and the Universidad de Salamanca facilities. Laboratory colonies were kept at 25 ± 1 °C, 55-80% RH, with a 16:8 h L:D photoperiod, in several boxes ($50 \times 50 \times 50$ cm methacrylate with a cloth-covered window in the lid) with water, sucrose solution and *Ephestia kuehniella* Zeller (Lepidoptera Pyralidae) eggs as a nutritional supplement, and a pot with soil substrate with carnations as host plant.

Bemisia tabaci (Gennadius) nymphs (Hemiptera Aleyrodidae) and *F. occidentalis* larvae (Thysanoptera Thripidae) came from populations originally collected on carnation plants from Viveros Devís (Valencia, Spain). Adults of these species were kept at the same climatic conditions as *D. geniculatus*. Inside the boxes water, sucrose solution and carnations were present as described above.

Experimental procedure

Adult mirids and prey used in the experiments were collected from laboratory colonies. In all cases, the adult mirids were collected when they were less than one-day-old and used for the experiment when they were five days old.

D. geniculatus adults (n = 13 ♀♀ + 13 ♂♂) were introduced into a $50 \times 50 \times 50$ cm methacrylate box (with a cloth-covered window in the lid) together with four carnation plants in a climate-controlled chamber (25 ± 1 °C, 60 ± 5% HR, 16:8 h L:D photoperiod) for one day. Four replicates were performed for each experiment. Then, mirid adults were removed, and the aerial parts of the plants were checked, under a LeicaMZ125 binocular microscope, for oviposition scars (about 1 mm

long) and cut into small sections (about 2×2 mm), each containing one egg that was less than 24 hours old. Each plant section was placed with one egg in a Petri dish (10 cm diameter) on a fine layer (3 mm) of agar (2%, w/v) and examined daily until mirid nymphs appeared. The nymphs that emerged were placed individually into clear, covered plastic cages (4 cm diameter at the bottom, 5.4 cm at the top, 3 cm high and ventilated with insect gauze with a tiny mesh size) and held in the climate chamber under the same controlled conditions. In each cage, stem and leaf samples from the host plant and water in an Eppendorf tube fitted with a cotton wick were provided.

Experiment 1: *Dicyphus geniculatus* juvenile development and survival

To evaluate the influence of prey on the biology of *D. geniculatus*, 15 newly emerged mirid nymphs were placed individually in plastic cages, which were supplied daily with a portion of carnation leaf, water and at least 50 prey (*B. tabaci* nymphs or *F. occidentalis* larvae, both at any stage), which were considered as the two treatments. The control treatment consisted of individualised carnation leaf portions and water only, without any type of prey. These mirid nymphs were examined daily until death or final moult to adult, and their development times (days), survival (expressed as %) and sex ratio were calculated.

Experiment 2: *Dicyphus geniculatus* reproduction

To evaluate the reproductive parameters of the insect, *i.e.*, realised fecundity and adult longevity, 30 couples (male and female) of newly emerged adults of *D. geniculatus* were individualised in the plastic cages with prey (nymphs of *B. tabaci* or larvae of *F. occidentalis*), and leaves of the host plant with petiole and water *ad libitum*, or with leaves of the host plant with petiole and water only, in the absence of prey. Leaves were changed and new prey was offered every two days until adult death.

Both experiments were repeated three times with a new batch of nymphs and adults over time.

Data analysis

Three-way factorial ANOVA (with a post-hoc Tukey HSD test for pairwise comparisons) was used to process data from both experiments, in which the random factor was always the "repetition period". In Experiment 1, the influence of the fixed factors "nymphal instar" and "prey availability" (*i.e.*, prey type-without prey) on the nymphal survival (%) of *D. geniculatus* was tested; also, the influence of the fixed factors "food source" and "sex" on the nymphal development time of *D. geniculatus* was tested. In Experiment 2, the effect of the fixed factors "prey diet" and "sex" on adult longevity was tested. Additionally, two-way factorial ANOVA (with a post-hoc Tukey HSD test for pairwise comparisons) was used to process data from Experiment 2 to test the effect on realised fecundity of the fixed factor "prey availability", taking as random factor the "repetition period". In Experiment 1, sex ratio (presented as proportion male: ♂♂/♀♀+♂♂) of adults was compared to a null hy-

pothesis of 1:1 using a χ^2; this test was used to compare sex ratio after consumption of different prey types. All variables were distributed normally and were not transformed prior to analyses. In addition, the distributions of residuals were approximately normal. Values are reported as means ± SE. Analyses were performed using the IBM SPSS statistical software package (v2.0; critical p-value used: 0.05).

Results

Experiment 1: *Dicyphus geniculatus* juvenile development and survival

The three-way ANOVA [σ^2 (residual variance): 0.012, σ_B^2 (block variance): $7.1/10^6$] revealed that survival of nymphs (table 1) differed significantly with respect to nymphal instar ($F_{4, 26} = 9199.69$; $p \leq 0.001$) and prey availability ($F_{2, 26} = 34392.97$; $p \leq 0.001$). An additional Tukey's HSD test revealed significant differences at the 95% confidence level amongst all nymphal instars and also with different prey types (table 1). Furthermore, the three-way ANOVA did not reveal any significant interaction between the factors (nymphal instar/prey availability) and survival of nymphs ($F_{6, 26} = 6490.25$; $p \leq 0.001$).

Concerning the nymphal development time (table 2), the three-way ANOVA [σ^2 (residual variance): 0.46, σ_B^2

(block variance): $2.3/10^5$] revealed that this variable differed significantly with respect to sex ($F_{1, 188} = 13.17$; $p \leq 0.001$) and prey type ($F_{1, 188} = 68.42$; $p \leq 0.001$). Furthermore, the three-way ANOVA did not reveal any significant interaction between the factors (nymphal instar/prey availability) and survival of nymphs ($F_{1, 188} = 0.622$; $p = 0.431$).

The sex ratio corresponding to both feeding regimes "with *B. tabaci* prey" and "with *F. occidentalis* prey" did not differ from 1(♂♂):2(♀♀+♂♂) ["with *B. tabaci* prey" (37/53+37 = 0.41), $\chi^2 = 1.434$, df 1, $p = 0.231$; "with *F. occidentalis* prey" (42/50+42 = 0.46), $\chi^2 = 0.200$, df 1, $p = 0.655$]. Also, the sex-ratio did not differ with respect to prey type (*B. tabaci* or *F. occidentalis*) ($\chi^2 = 0.564$, df 1, $p = 0.453$).

Experiment 2: *Dicyphus geniculatus* reproduction

With respect to adult longevity (figure 1), the three-way ANOVA [σ^2 (residual variance): 70.39, σ_B^2 (block variance): $4/10^5$] revealed that longevity differed significantly in terms of prey availability ($F_{2, 534} = 58.89$; $p \leq 0.001$). Also, longevity was different for each sex within each feeding regime ($F_{1, 534} = 14.13$; $p \leq 0.001$). An additional Tukey's HSD test revealed significant differences at the 95% confidence level between feeding regime, i.e. without prey, compared to *B. tabaci* / *F. occidentalis* diets. However, no significant differences were found (figure 1) between prey feeding re-

Table 1. Survivorship (expressed as a percentage: %) of nymphal instars (N_1-N_5) of *D. geniculatus* in carnation plants at 25 ± 1 °C, 55-80% RH, and 16:8 h L:D photoperiod with different prey and without prey. The survival of nymphs differed significantly with respect to nymphal instar ($F_{4, 26} = 9199.69$; $p \leq 0.001$) and prey availability ($F_{2, 26} = 34392.97$; $p \leq 0.001$).

Nymphal instars (%)	Carnation plants		
	Without prey	With prey	
		Bemisia tabaci	*Frankliniella occidentalis*
	(n = 45)	(n = 45)	(n = 45)
N_1	80	95	92
N_2	28	79	74
N_3	8	76	73
N_4	-	70	67
N_5	-	66	63
Total	-	26.5	22.1

Table 2. Development time for male and female nymphal instars (N_1-N_5) of *D. geniculatus*, (days; mean ± SE), in carnation plants at 25 ± 1 °C, 55-80% RH, and 16:8 h L:D photoperiod with different prey and without prey. The nymphal development time differed significantly with respect to sex ($F_{1, 188} = 13.17$; $p \leq 0.001$) and prey type ($F_{1, 188} = 68.42$; $p \leq 0.001$).

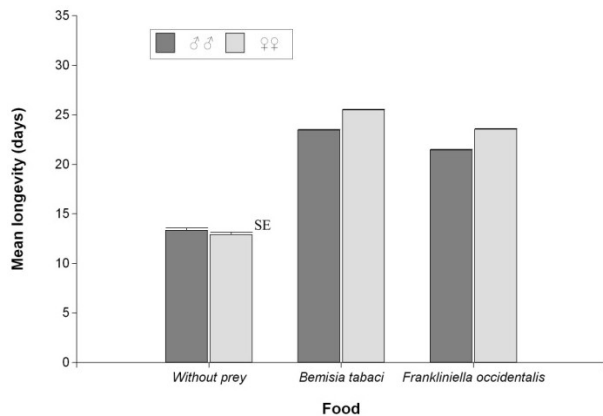| Nymphal instars	Carnation plants				
	Without prey	With prey			
		Bemisia tabaci		*Frankliniella occidentalis*	
	(n = 45)	♂♂ (n = 21)	♀♀ (n = 24)	♂♂ (n = 22)	♀♀ (n = 23)
N_1	3.6 ± 0.3	3.1 ± 0.6	3.2 ± 0.5	3.1 ± 0.4	3.3 ± 0.1
N_2	5.1 ± 0.2	5.2 ± 0.4	5.8 ± 0.5	6.4 ± 0.2	7.2 ± 0.1
N_3	3.8 ± 0.2	3.2 ± 0.3	4.1 ± 0.2	3.9 ± 0.3	3.3 ± 0.6
N_4	-	2.2 ± 0.4	2.3 ± 0.3	3.7 ± 0.3	3.2 ± 0.4
N_5	-	3.3 ± 0.6	2.4 ± 0.5	3.8 ± 0.7	4.2 ± 0.2
Total	-	17.9 ± 0.6	18.9 ± 0.7	21.4 ± 0.5	22.1 ± 0.8

Figure 1. Mean adult longevity of *D. geniculatus* (days) in carnation plants at 25 ± 1 °C, 55-80% RH, and 16:8 h L:D photoperiod with different prey and without prey. The longevity differed significantly in terms of prey availability ($F_{2, 534}$ = 58.89; p ≤ 0.001) and also within each feeding regime ($F_{1, 534}$ = 14.13; p ≤ 0.001).
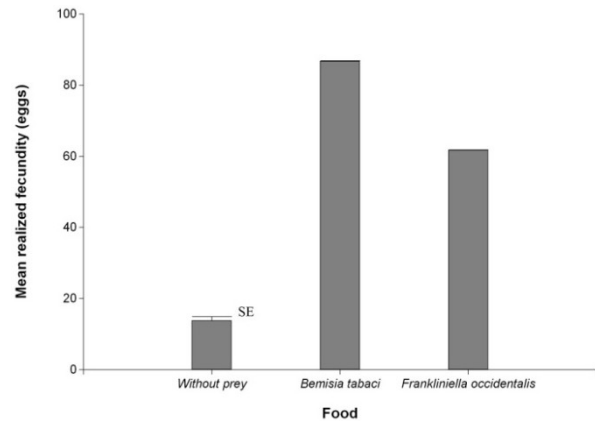

Figure 2. Mean realised fecundity (eggs) of *D. geniculatus* in carnation plants at 25+ 1 °C, 55-80% RH, and 16:8 h L:D photoperiod with different prey and without prey. This variable differed significantly with respect to prey availability ($F_{1, 267}$ = 44504.92; p ≤ 0.001).

gimes (*B. tabaci* vs. *F. occidentalis*). Furthermore, the three-way ANOVA did not reveal any significant interaction between factors (prey availability / sex) and adult longevity ($F_{2, 534}$ = 0.820; p = 0.441).

With respect to realised fecundity (figure 2), the two-way ANOVA [σ^2 (residual variance): 38.44, σ_B^2 (block variance): 0.08] revealed that this variable differed significantly with respect to prey availability ($F_{1, 267}$ = 44504.92; p ≤ 0.001). An additional Tukey's HSD test revealed significant differences at the 95% confidence level among all feeding regimes (without prey, with *B. tabaci* and with *F. occidentalis*).

Discussion and conclusions

True bugs may be zoophytophagous (Wheeler, 2001), and the importance of plant and animal nutrients for development and survival is variable depending on plant, prey and zoophytophagous species (Naranjo and Gibson, 1996). Accordingly, feeding regime and type of prey have a great influence on *D. geniculatus* life cycle and performance, as it has already been observed for other dicyphine species and is further discussed.

Adults of *D. geniculatus* can survive on carnation plants without the availability of prey for about 12-13 days. Nevertheless, this species is unable to complete its development without any prey. Whitefly nymphs and thrips larvae were necessary, as prey, for *D. geniculatus* to complete its nymphal development, showing that *D. geniculatus* requires an animal component in its diet for development. The same results were observed for *N. tenuis* (Urbaneja *et al.*, 2005) and *D. errans* (Arvaniti *et al.*, 2014).

Other zoophytophagous dicyphines can develop into adults feeding only on plants, as is the case for *D. tamaninii* (Lucas and Alomar, 2001). However, the response of zoophytophagous dicyphine species to diet is not homogeneous, even within the same insect species.

M. pygmaeus reared on strict phytophagy may reach adulthood (Lucas and Alomar, 2001; Perdikis and Lykouressis, 2000) or not (Ingegno *et al.*, 2011).

The effect of diet on dicyphine performance depends on plant, prey and zoophytophagous insect species and on the type and/or amount of plant and/or animal food, under the influence of abiotic factors (Sánchez, 2008). In the case of plants, every part provides different nutritional qualities (Lucas and Alomar, 2001). Prey availability determines insect establishment on host plants (Ingegno *et al.*, 2011), and in a more general sense, prey consumption influences insect performance (Tavella and Arzone, 1996; Perdikis and Lykouressis, 1997; 2000). In the present study, realised fecundity of *D. geniculatus* was significantly much lower in an exclusively herbivorous diet and different depending on prey type, as reported for other dicyphine species (Urbaneja *et al.*, 2005; Hatherly *et al.*, 2008).

Switching from plant to prey consumption and *vice versa* is a crucial item to evaluate *D. geniculatus* utility as pest predator. *N. tenuis* (El-Dessouki *et al.*, 1976; Calvo and Urbaneja, 2003; Calvo *et al.*, 2009) and *D. tamaninii* (Gabarra *et al.*, 1988; Albajes and Alomar, 1999; Castañé *et al.*, 2003) have been shown to damage the plants when prey is scarce, thus entailing the monitoring of a predator's population to keep it below plant damage risk densities (Alomar and Albajes, 1996), although it has been shown that yield may not be affected by the injuries inflicted by a zoophytophagous beneficial (Sánchez and Lacasa, 2008). Those generalist predators may successfully control several pests already reported in association with carnations such as mites, spider mites, thrips, aphids, scales, cutworms and caterpillars, as well as whiteflies and leaf-miners, observed to be consumed by *D. geniculatus* on *D. caryophyllus*. There is thus a common, already known scenario to be taken into account when using *D. geniculatus*, a polyphagous zoophytophagous dicyphine. The benefits of carnation pest biological control and the risk of carna-

tion damage when prey declines have to be properly evaluated (Albajes and Alomar, 1999). In the case of *N. tenuis*, benefits outweigh risks (Urbaneja *et al.*, 2005).

D. caryophyllus has a waxy, smooth epidermis, which makes the plant more vulnerable to pesticides (Belda and Moerman, 2008). Predatory mites efficiently control red mites, spider mites and thrips, and some successful IPM on carnations have been reported (Gullino and Wardlow, 1999) in relationship to the two latter pests. However, carnation colonisation is difficult for predatory mites, as they do not easily adhere to smooth surfaces (Belda and Moerman, 2008), an observation fitting generalist predators (Krimmel, 2014). Lacewings have been proved to be useful in limiting aphid populations in carnation IPM cultures (Gullino and Wardlow, 1999). Aphid populations may be controlled by the cecydomiid *Aphidoletes aphidimyza* (Rondani) when temperature in the crops is above 16 °C, but this is not the case for certain periods of the year, either due to winter temperatures, or because carnation is cultivated at low temperatures (Hernández, 1983). In addition, glabrous plants (those with little hair) are less attractive to predators, as they lack extra food in the form of carrion or pollen usually entrapped in hairy plants (Krimmel, 2014). However, predatory mirid bugs colonise smooth sweet pepper plants and successfully control the pepper pests: *M. pygmaeus* controls *F. occidentalis* in the Netherlands (Messelink *et al.*, 2011), as well as *M. persicae* in the Netherlands (Messelink *et al.*, 2011), Greece (Perdikis and Lykouressis, 2004) and Spain (Pérez-Hedo and Urbaneja, 2015). In Spain, *N. tenuis* and *D. maroccanus* control *M. persicae* (Pérez-Hedo and Urbaneja, 2015).

D. geniculatus opens a new perspective on pest management on hairless ornamental host plants. By colonising carnations, *D. geniculatus* may contribute to the biological control of carnation pests, adding to the positive effects of previously implemented beneficials (Belda and Moerman, 2008). Although some successful IPM programs have been implemented (Gullino andWardlow, 1999), several carnation pests have to be managed by pesticide spraying (INFOAGRO, 2016). Urban ecosystem services deserve increasing research (Kremer *et al.*, 2015), and the implementation of beneficials may contribute to the final goal of achieving the best environmental and human health conditions in urban areas. Nevertheless, our results are still preliminary, and further research is needed to evaluate the feasibility of carnation pest management using *D. geniculatus* in conservation or augmentative biological control.

Acknowledgements

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