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ORIGINAL ARTICLE

A preventive strategy for the control of aphids in sweet pepper using lacewings and micrococcinelid beetles

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Abstract Aphids are a serious threat to sweet pepper crops. Due to increasing aphid resistance to insecticides and rising demand for pesticide-free products, pest management is currently based on biological control programs. However, growers often face economic losses because these programs have limited success, largely due to poor establishment of natural enemies when aphid populations are low. This study aimed to evaluate new natural enemies for early-season aphid control. Two candidates were selected to be used against the aphid *Myzus persicae* (Sulzer) (Hemiptera: Aphididae): the micrococcinellid *Scymnus interruptus* (Goeze) (Coleoptera: Coccinellidae) and the brown lacewing *Micromus variegatus* (Fabricius) (Neuroptera: Hemerobiidae). Two studies were conducted to assess their potential as aphid biocontrol agents. Firstly, different alternative food sources that might help for supporting their establishment in the absence of aphids were tested. Secondly, in a greenhouse experiment conducted in walk-in cages, natural enemies were released under preventive conditions (long aphid absence). Their establishment, complementarity, and effectiveness were evaluated during 5 weeks, after periodical low aphid infestations. Our results exposed that supplemental food sources must be provided for the survival of *M. variegatus* when aphids are absent in the crop. However, *S. interruptus* could survive in absence of aphids in the presence of sweet pepper flowers for a long period. Our greenhouse trial showed *S. interruptus* provided better aphid control than *M. variegatus* but the best results came from combining both species. Overall, our study demonstrated the potential of *M. variegatus* and *S. interruptus* as preventive biocontrol agents against aphids in sweet pepper crops.

Key words biological control strategies; *Micromus variegatus*; *Scymnus interruptus*

Introduction

Over the last decade, preventive biological control programs have emerged as a key strategy for successful pest control in protected crops (van Lenteren & Nicot, 2020). In contrast to curative approaches, where natural enemies are introduced post-pest invasion, preventive biological control programs rely on releasing and establishing biocontrol agents in the crop (standing army concept) prior to pest infestation (Messelink *et al.*, 2014; Pijnakker *et al.*, 2017; Pijnakker *et al.*, 2020). Due to the absence of pests, the presence of alternative food sources is essential to maintain natural enemy populations in the crop (Landis *et al.*, 2000). The increased use of generalist predators that feed on a variety of food sources has certainly been pivotal for the success of preventive biocontrol programs (Messelink *et al.*, 2012b).

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For many omnivorous biocontrol agents, food sources can be provided by the crop itself, such as floral resources or plant tissues (Heimpel & Jervis, 2005; Wäckers *et al.*, 2007; Pappas *et al.*, 2015; Salas, 2019). For example, zoophytophagous mirid predators may resort to feeding on the plant itself in the absence of prey and persist in the crop when prey is scarce (Pappas *et al.*, 2019; Silva *et al.*, 2022). Generalist predatory mites also feed on pollen, allowing them to establish and persist in the crop before pests arrive (McMurtry & Croft, 1997; Pijnakker *et al.*, 2020). When alternative food sources are lacking in the crop or they cannot fulfill the nutritive requirements of biocontrol agents, supplemental foods can be provided. The vast majority of the supplemental foods currently used in the horticultural crops were originally developed for arthropod mass rearing (De Clercq, 2008). Supplemental foods can be natural, factitious or artificial, and can be of animal or plant origin (Landis *et al.*, 2000; Gurr *et al.*, 2017; Benson & Labbe, 2021). One of the most commonly used natural food source is pollen. This food source can be added to a nonflowering crop via banker plants (Huang *et al.*, 2011). Alternatively, pollen can be collected from anemophilous plants, such as maize or cattail (*Typha* spp.) and then dispersed on the crop itself (Pijnakker *et al.*, 2016; Pijnakker *et al.*, 2020). Pollen is a high quality food source containing free amino acids, proteins, lipids, sterols, carbohydrates, vitamins and minerals (Wäckers, 2005; De Clercq, 2024), and can be successfully used to establish predatory mite populations (Messelink *et al.*, 2009; Gerson & Weintraub, 2012; Adar *et al.*, 2014; Leman & Messelink, 2015; Ferreira *et al.*, 2020; Pijnakker *et al.*, 2020). Additionally, other biocontrol agents, such as heteropterans, coccinellids or parasitoids can also employ pollen as a valuable resource to increase longevity (Hagen, 1962; Zhang *et al.*, 2004; Wong & Frank, 2013). The use of factitious food also plays a key role in the establishment of natural enemies in the absence of prey. The term "factitious" refers to food sources that do not naturally co-occur with the species to be fed. Decapsulated dry cysts of the brine shrimp *Artemia franciscana* Kellogg (Anostraca: Artemiidae) and eggs of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) are among the most commonly used factitious prey. They are released in the crop as a valuable alternative food for a wide range of predators such as predatory mites, coccinellids, mirids, chrysopids, or anthocorids (Castañé *et al.*, 2006; Riddick, 2009; Messelink *et al.*, 2015; Owashi *et al.*, 2020; Pijnakker *et al.*, 2020; Mouratidis *et al.*, 2023). Furthermore, the provisioning of sugar resources, such as sucrose, can also be used to support the establishment of parasitoids and hoverflies that require a continuous carbohydrate intake to survive and reproduce (Azzouz *et al.*, 2004; Tena *et al.*, 2015; Leman *et al.*, 2023).

The implementation of preventive biological control programs is particularly important for the management of key pests that grow exponentially, such as aphids (Williams *et al.*, 1999; Costamagna *et al.*, 2007; van Emden & Harrington, 2017). Aphids are among the most destructive pests in horticultural crops worldwide (Mani, 2022). They can cause severe damage to the crop when feeding, weakening plant growth and can act as virus vectors, transmitting plant diseases that further reduce yield and quality (Simon & Peccoud, 2018; Singh & Singh, 2021; Luo *et al.*, 2022). Currently, biological control of aphids in greenhouse crops relies primarily on periodic releases of aphidophagous predators such as the gall midge *Aphidoletes aphidimyza* (Rondani) (Diptera: Cecidomyiidae), parasitoids of the genera *Aphidius* and *Aphelinus* (Hymentopera: Braconidae), and to a lesser extent macrococcinellids and green lacewings. Although *A. aphidymiza* and parasitoids are released preventively, curative releases are the most effective and economically feasible strategies due to the inability of these biocontrol agents to establish when aphids are absent or scarce (Lopes *et al.*, 2009; La-Spina & Buitenhuis, 2017). Although banker plants with noncrop-threatening aphid species could be an option, the high aphid demand by *A. aphidymiza* to complete its life cycle and the arrival of hyperparasitoids limit their adoption (Fernández & Nentwig, 1997; Boulanger *et al.*, 2019; Messelink *et al.*, 2020). In this context, the addition of novel biocontrol agents with preventative release potential would be of great value to the current biological control strategies for aphids.

Previous studies have reported the key role of micrococcinellids in early aphid control. In particular, species belonging to the genus *Scymnus* (Coleoptera: Coccinellidae) such as *Scymnus interruptus*, which are able to prevent aphid outbreaks in Mediterranean citrus crops (Gómez-Marco *et al.*, 2016; Bouvet *et al.*, 2019). *S. interruptus* exploits aphid colonies at early stages and is able to persist at low prey densities (Beltrà *et al.*, 2018). These traits combined with a high longevity, high recruitment rates and the ability to exploit alternative prey such as spider mites, mealybugs and scale insects, make *S. interruptus* a potential candidate for the development of an effective preventive biocontrol program against aphids (Tawfik *et al.*, 1973; Bouvet *et al.*, 2019; Bouvet *et al.*, 2021). In addition to micrococcinellids, hemerobiids, commonly known as brown lacewings, may also be valuable candidates for preventive aphid control. This might be the case for *Micromus variegatus* (Fabricious), which has been reported to occur spontaneously in sweet pepper crops and ornamental greenhouses with low aphid infestations (van Schelt *et al.*, 2005; Messelink personal observations). Unlike other lacewings frequently used in biocontrol strategies, both adult and larval stages of hemerobiids feed on aphids, which provides an advantage for pest suppression (Messelink *et al.*, 2012a; Rocca & Messelink, 2017).

In this study, we evaluated the potential of *M. variegatus* and *S. interruptus* as candidates for preventive aphid control in greenhouse crops. To address this, we first evaluated the survival of both species on different food sources that could potentially be implemented in the crop to support their persistence. Subsequently, in a greenhouse trial, we evaluated their establishment and aphid control efficacy when released prior to aphid infestation, in both single-species and combined-species treatments.

Materials and methods

Insect cultures

The brown lacewing *M. variegatus* was collected from an Alstroemeria crop in a greenhouse compartment of Wageningen University and Research in Bleiswijk (52°01′55.0″N, 4°31′51.3″E) (The Netherlands), where it occurred spontaneously. Individuals of the micrococcinellid *S. interruptus* were collected from rose bushes in Maastricht (50°50′44.5″N, 5°41′25.8″E) (The Netherlands). Both predators were subsequently reared in climate chambers (Snijders Micro Clima-series^{TM}, Tilburg, The Netherlands) for more than 20 generations and under constant conditions (25 °C, 70% RH and a 16 h L : 8 h D). Both species were fed *ad libitum* with the green peach aphid *Myzus persicae* (red phenotype).

The aphids used in the experiments belonged to *M. persicae* species (red phenotype) and were reared for more than 20 generations on 50 cm high pesticide-free sweet pepper plants (*Capsicum annuum* L., cv. Maranello), Enza Zaden (Enkhuizen, The Netherlands). Aphid colonies were maintained under greenhouse conditions at 25 ± 2 °C, 65% ± 10% RH and an ambient photoperiod.

Laboratory experiment: effect of different diets on M. variegatus and S. interruptus survival

Arenas consisted of a small plastic cup (6 cm diameter, 6 cm depth) with a 2 cm layer of water agar (15 g/L). On the top of the agar layer, a 6 cm diameter sweet pepper leaf was embedded with its abaxial side exposed. Cups were closed with a plastic lid. Ventilation was provided by a 4.5 cm diameter hole in the lid, covered with fine mesh. The sweet pepper leaves were pesticide-free and belonged to the cultivar Maranello.

The survival of 48-h-old individualized *M. variegatus* and *S. interruptus* females was evaluated during three months (90 d) on eight different diets: (i) sweet corn pollen (*Zea mays* L. var. Saccharata cv. Conqueror) dried and stored at −20 °C for approximately 4 years, (ii) fresh sweet pepper pollen (*C. annuum* L., cv. Maranello), (iii) cattail pollen (*Typha latifolia* L.) dried and stored at −20 °C, provided by Biobest (Belgium), (iv) *Ephestia* eggs, provided by Koppert (The Netherlands), (v) freeze-dried decapsulated cysts of *A. franciscana*, provided by Biobee (Israel), (vi) three freshly harvested open sweet pepper flowers, (vii) ≈ 150 mixed instars of *M. persicae* aphids, and (viii) no food. Food was supplied *ad libitum* and replaced every 3 d. All cups included a piece of cotton wool soaked with water. Arenas were replaced once a week and both insect survival and oviposition were recorded every 2 d. Twelve replicates were performed for each diet for *M. variegatus* and 10 replicates per diet for *S. interruptus*.

Greenhouse experiment: establishment, complementarity and efficacy of M. variegatus and S. interruptus in aphid control

Plants and greenhouse conditions The greenhouse trial was conducted in two 96 m^2 adjacent compartments at the Business Unit Greenhouse Horticulture of Wageningen University & Research (Bleiswijk, The Netherlands) from week 16 (April 21) until week 25 (July 23) in the year 2021. This schedule was designed to simulate the natural early-season arrival of aphids in the crop, aligning with their typical colonization patterns observed under commercial greenhouse conditions in the Netherlands. In the ninth week, 16 walk-in cages of 1 m × 2 m × 2 m made of fine insect gauze (mesh size 0.22 mm × 0.31 mm) were installed and evenly distributed over the two compartments. In each cage four pesticide-free sweet pepper plants (*C. annuum* cv. Margrethe) of 7 weeks old were placed on a 1 m rockwool slab. Once the plants were introduced into the cages, they were grown according to a three-stems-per-plant system, and each plant stem was tied and supported by a rope attached to the cage ceiling. Plants were drip irrigated and watered daily with a nutrient solution specific for sweet pepper crops (Sonneveld & Voogt, 2009). The average temperature and relative humidity were 23 ± 3 °C and 74%, respectively, with a natural photoperiod. Both temperature and relative humidity were recorded every 5 min throughout the experiment using a climate recorder (Hoogendoorn Growth Management, Vlaardingen, The Netherlands).

Experimental set up and sampling procedure The experiment consisted of four different treatments: (i) control (no natural enemy releases), (ii) releases of *M. variegatus*, (iii) releases of *S. interruptus*, and (iv) releases of both *M. variegatus* and *S. interruptus*. The experiment was conducted in two adjacent compartments in a randomized complete block design with four replicates per treatment and two blocks per compartment.

The experiment started 7 weeks after cage and plant installation (week 16). Plants were all flowering and reached a height of approximately 1 m. From week 9 (plant introduction into cages) to week 16, plants were monitored weekly to ensure the absence of pests or natural enemies. In week 16, both natural enemies were introduced preventively. In cages assigned to the *M. variegatus* treatment, six couples of 1-week-old adults were released and a volume of 1.5 mL of *E. kuehniella* eggs was spread over the plants (around 0.2 g per plant) as an alternative food source. This food supply was repeated weekly until week 20. In cages assigned to the *S. interruptus* treatment, 12 couples of 1-week-old adults were released, but no additional food was added because *S. interruptus* adults survive for long periods on pollen and nectar from pepper flowers (results obtained from the laboratory experiment). In the cages where *M. variegatus* and *S. interruptus* were combined, the dosage of both of them was the same as in the treatments where they were released alone. In week 18, the same procedure as in week 16 was followed, and new natural enemies were released with the same dosage (this was the second introduction). At week 20, 4 weeks after the first natural enemy release and 2 weeks after the second release, all plants were infested with the aphid *M. persicae* (red phenotype). A small piece of pepper leaf with 10 aphids (from second instar nymphs to adults) was added to each stem. This resulted in 30 aphids per plant and 120 aphids per cage. Aphid infestations were repeated 1, 2, and 3 weeks later (weeks 21, 22, and 23) using the same procedure described above.

Aphid and natural enemy densities were assessed visually once a week, starting 1 week after the first aphid infestation (week 21) and continuing for four more weeks (weeks 22, 23, 24, and 25). The number of natural enemies (eggs, larvae, and adults) and the number of aphids were recorded on six leaves per plant, two leaves per stem. The leaves were randomly selected, but two were from the top, two from the middle and two from the bottom of the plant. Therefore, 24 leaves were counted per cage. In the case of *S. interruptus*, eggs were not recorded because their size is too small to be assessed by naked eye or a hand magnifying glass. Plants were pruned once a week and sweet peppers were harvested when the fruits were ripe, following standard protocols for sweet pepper crop production. Removed shoots and sweet peppers were left in the cages to allow potential predators to re-infest the crop.

Data analysis

The effect of different diets on the survival of *M. variegatus* and *S. interruptus* was examined by using a Kaplan-Meier analysis with the "Survival" package in R (survfit function). The log-rank test was performed using the survdiff function to compare the survival curves between different diets in each species and Bonferroni correction was applied to adjust for multiple comparisons.

In the greenhouse experiment, aphid densities were analyzed using a Generalized Linear Mixed Model (GLMM) with a Poisson distribution and a log link function. The appropriateness of the distribution was evaluated by assessing overdispersion and checking model fit through residual diagnostic plots from the DHARMa package (Hartig, 2022). The GLMM was fitted using the "glmmTMB" package (Brooks *et al.*, 2017). Treatment was considered as a fixed effect and replicate (cage) and time as crossed random effects. Subsequently, post hoc pairwise comparisons were conducted using estimated marginal means (emmeans), from the "emmeans" package, with Tukey's adjustment for multiple comparisons applied to the model's log-scale estimates (Lenth, 2025). All data processing was carried out using the R 4.0.2 statistical software (R Core Team, 2021).

Results

Laboratory experiment: effect of different diets on M. variegatus and S. interruptus survival

Survival of both *M. variegatus* and *S. interruptus* differed among diets (Fig. 1). *Micromus variegatus* showed the lowest survival on the pollen diets (Fig. 1A), with no significant differences compared to the treatment where no food was added. In the diets of corn pollen, sweet pepper pollen and cattail pollen all individuals were dead after 6, 10 and 13 d. Survival was 12 d when no food was added. The highest survival rates were achieved with the diets containing *Ephestia* eggs, followed by aphids, sweet pepper flowers and *Artemia*. Although there were no significant differences among these treatments, survival rates were significantly different from the pollen

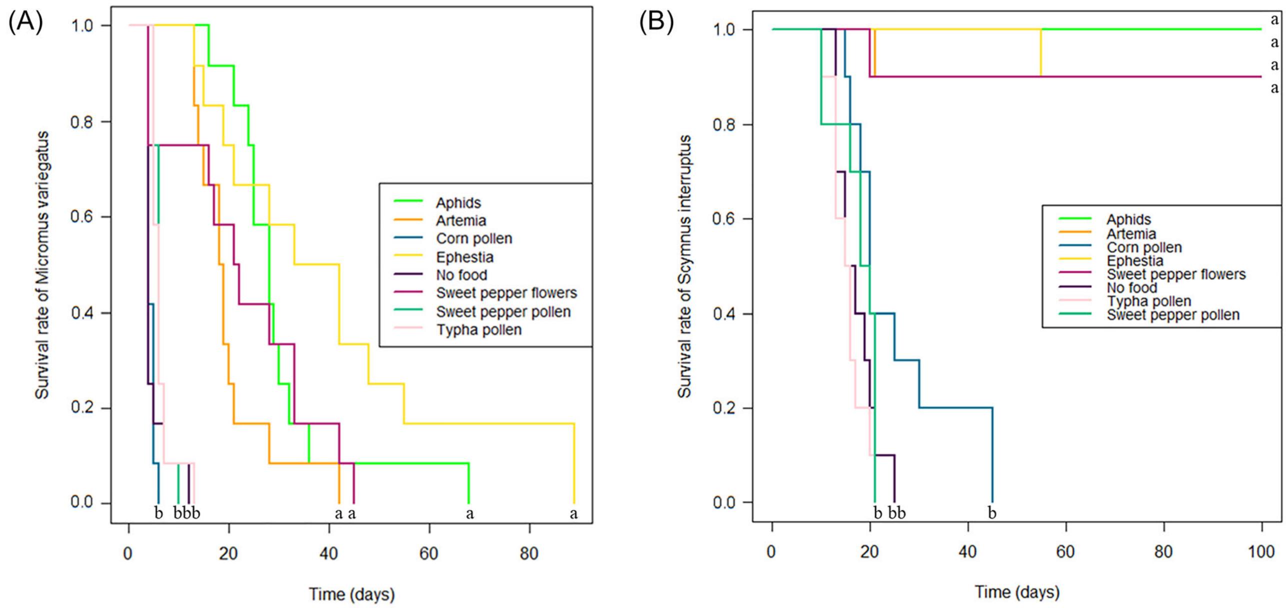

Fig. 1 Survival rate of (A) *Micromus variegatus* and (B) *Scymnus interruptus* females over time on eight different diets. Different letters indicate significant statistical differences among treatments ($P < 0.05$).

diets and control treatment without food ($\chi^2 = 144$, df $= 7$, $P < 0.001$). In the treatment with sweet pepper flowers and *Artemia*, half of the individuals were dead at around 22 d but survival was up to 40 d in both treatments. When aphids were provided, individuals survived up to 70 d with half of the individuals dying around day 32. The highest survival rate was achieved in the *Ephestia* diet treatment, where individuals survived up to 90 d and half of the individuals died around day 42. Throughout the whole experiment, oviposition was recorded only twice for *M. variegatus* when they were fed with aphids.

S. interruptus showed significant differences in survival rates among diet treatments ($\chi^2 = 96.2$, df $= 7$, $P < 0.001$) (Fig. 1B). In the diets of sweet pepper pollen, cattail pollen, no food and corn pollen, all individuals were dead after 21, 21, 25, and 45 d, respectively, and no significant differences were found among them. The highest survival rates were achieved in the diets of *Artemia*, sweet pepper flowers, aphids and *Ephestia*, and there were no significant differences among them. Differences were found when aphids, *Artemia*, *Ephestia* or sweet pepper diets were compared with pollen diets and no food supply. When *Ephestia*, *Artemia* or sweet pepper flowers were added, more than 90% of the individuals survived for more than 100 d. Throughout the whole experiment, *S. interruptus* eggs were only recorded when females were fed with aphids.

Greenhouse experiment

Aphid densities were significantly reduced by both *M. variegatus* and *S. interruptus* compared with the control ($\chi^2 = 18.49$, df $= 3$, $P < 0.001$). Although no significant differences were found among cages where the predators were released, aphid densities showed a trend of lower densities in the treatment of *S. interruptus* alone compared with cages where *M. variegatus* was released alone (Fig. 2). The combination of both natural enemies reduced aphid densities by almost 100%, with an average of less than one aphid per leaf throughout the whole experimental period. In cages where *S. interruptus* was released, aphid densities were similarly reduced and under control, with an average of three aphids per leaf at the end of the trial. In cages with *M. variegatus*, aphid densities were reduced by 80%, with an average of 140 aphids per leaf at the end of the experiment.

Micromus variegatus was recorded as adults or eggs, whereas larvae were absent throughout the whole experimental period in cages where it was released alone (Fig. 3A).

In contrast, the coccinellid *S. interruptus* successfully established. Either in the treatment where it was released alone (Fig. 3B) or in the treatment where it was combined with *M. variegatus* (Fig. 3C). Larvae were recorded from the first sampling week until the end of the experiment (with a peak of more than four individuals per cage) in

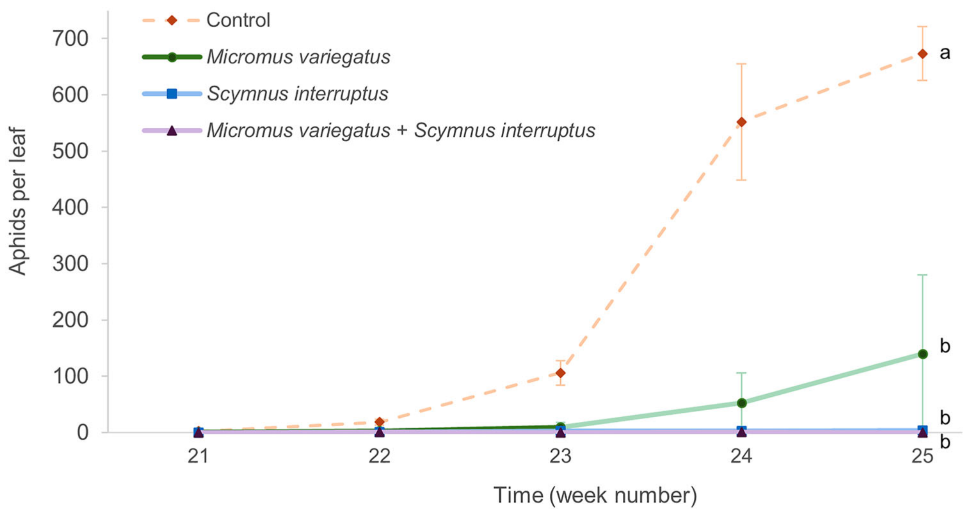

Fig. 2 Mean number (±) SE of aphids per leaf through time. Natural enemies were released in weeks 16 and 18. *Ephestia* eggs were provided as a supplemental food once a week in weeks 16, 17, 18, 19, and 20 in cages with *M. variegatus*. Plants were infested with the aphid *Myzus persicae* in weeks 20, 21, 22, and 23. Different letters indicate significant statistical differences among treatments ($P < 0.0001$).

the *S. interruptus* treatment. In cages where *S. interruptus* and *M. variegatus* were combined, the density of *S. interruptus* larvae was lower, with an average of one larva per cage.

Our results showed that both predators survived for more than 2 weeks in the absence of aphids feeding on alternative food sources, and ultimately had a strong suppressive effect on aphids.

Discussion

Our results show that *M. variegatus* and *S. interruptus* have potential to be used as preventive biocontrol agents for aphid control in sweet pepper crops. Our laboratory experiments indicate that both predators were able to survive for extended periods relying on alternative food sources, except when fed on pollen diets. Both adult hemerobiids and micrococcinellids are considered omnivorous insects that consume a variety of prey, honeydew and pollen (Stelzl, 1991; Hodek *et al.*, 2012; Devetak & Klokočovnik, 2016). However, our study suggests that if *M. variegatus* or *S. interruptus* consume only corn, cattail or sweet pepper pollen, these diets may not provide the necessary nutrients to support longevity. Unlike other food sources, pollen is mainly composed of amino acids and lacks significant amounts of carbohydrates and lipids, which are the primary energy sources for many insects (Nicolson & Thornburg, 2007; Pijnakker *et al.*, 2020; Morales-Ramos *et al.*, 2022).

Neither *M. variegatus* nor *S. interruptus* laid eggs with any of the alternative diets. Although studies on the effect of alternative food are scarce for hemerobiids, it has been shown that females can oviposit in the absence of prey. For instance, *Sympherobius pygmaeus* (Rambur) oviposits with only water or 10% honey water after being 30 d on this diet (Yaila & Satar, 2013) and *Micromus tasmaniae* Walker oviposits on a diet based only on buckwheat flowers during 10 d (Robinson *et al.*, 2008). Based on our personal observations, cannibalism may be the reason why no eggs were recorded. In fact, eggs were observed in our cage trial prior to the introduction of aphids. *Scymnus interruptus* oviposited only on the aphid diet. For most coccinellids, the quantity and quality of the food source has a direct influence on the oviposition choice of the female. Aphids or honeydew do serve as cues for oviposition induction (Wright & Laing, 1980; Evans & Dixon, 1986; Fréchette *et al.*, 2006; Seagraves, 2009). However, because *S. interruptus* larvae do not feed on alternative food sources such as *Ephestia*, *S. interruptus* females will not recognize it as a potential food for their offspring. Therefore, they will refrain from oviposition.

In the greenhouse trial, our findings indicate that both predators were able to survive without aphids for over 2 weeks, relying on alternative food sources, and ultimately exerted a strong suppressive effect on aphid populations. *Scymnus interruptus* effectively prevented aphid population growth. Aphid densities in cages with *S. interruptus* remained below five individuals per leaf throughout

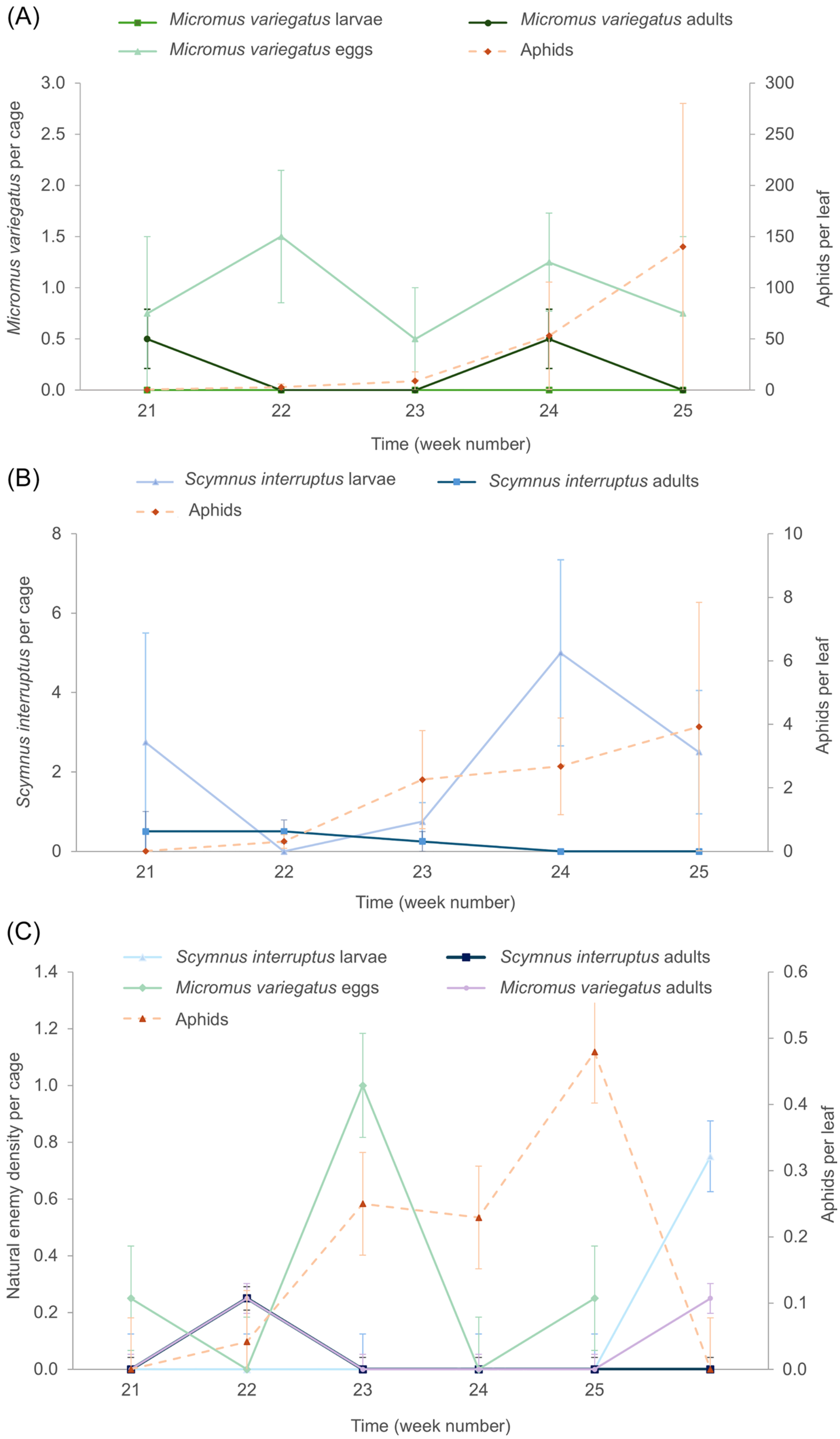

Fig. 3 Mean number (±) SE of natural enemies per cage and mean number (±) SE of aphids through time in cages treated with: (A) *M. variegatus*, (B) *S. interruptus* treatment, and (C) both natural enemies combined. Natural enemies were released in weeks 16 and 18. Plants were infested with the aphid *M. persicae* in weeks 20, 21, 22, and 23.

the 4-week period, even after the repeated aphid infestations. Furthermore, the predator established and was able to oviposit after 15–30 d of prey deprivation (larvae were recorded 1 week after the first aphid infestation). Micrococcinellids are key components in agricultural ecosystems to anticipate aphid outbreaks and arrive early on the crop when aphid populations are low (Bouvet *et al.*, 2019; Monzó *et al.*, 2019; Bouvet *et al.*, 2021). However, up to date, species of the genus *Scymnus* have only been evaluated as curative biocontrol agents or released after relatively high aphid infestations (100 aphids per coccinellid) (Allawi, 2006; Beltrà *et al.*, 2017; Borges *et al.*, 2022; Rosagro *et al.*, 2020), potentially masking the effectiveness of this predator at low aphid densities. Here, we show that a micrococcinelid predator can be effectively used as a preventive biocontrol agent against aphids in a horticultural crop.

In cages where *M. variegatus* was released, aphids were under control for three consecutive weeks (with less than 10 aphids per leaf). Hemerobiids are well-known as interesting aphidophagous insects because both larvae and adults are voracious predators (Neuenschwander & Hagen, 1980; Cole & Horne, 2006; Colares *et al.*, 2015). However, and despite their potential, few studies have investigated their role in biological control programs. Recently, Pekas *et al.* (2023) and Ntalia *et al.* (2022) showed that another hemerobiid species, *Micromus angulatus* (Stephens, 1836) can be successfully used as a biocontrol agent in sweet pepper and strawberry crops, when released curatively or just before the arrival of the pest. In this work, we show that another hemerobiid predator, *M. variegatus*, can successfully persist in the crop for an extended period of time (4 weeks), feeding on alternative food sources (such as *Artemia*, *Ephestia* and floral resources) and still be able to significantly reduce aphid densities.

When *S. interruptus* and *M. variegatus* were released in combination, aphid densities remained close to zero throughout the trial. Although both species were released at the same dosage as in cages where they were released alone, a better aphid control may indicate that there was no negative interaction between the two species. Hemerobiids have nocturnal habits while *S. interruptus* is an active diurnal predator (Miller, 1982; Ábrahám & Mészáros, 2006; Yadav *et al.*, 2009). This complementarity between their feeding habit periods may improve overall pest control by providing continuous predation coverage throughout the 24-h cycle.

In conclusion, our study showed that *M. variegatus* and *S. interruptus* are valuable candidates for preventive aphid control. According to our findings, these two predators can be used in an adult form in preventive releases for aphid control. While *S. interruptus* does not require any additional food source as long as floral resources are present in the crop, *M. variegatus* should be released either with a supplementary food, such as *Ephestia* or when flowers are abundant. It is important to note that this study was conducted on sweet pepper plants and the availability and quality of floral resources might vary in other crops. It should also be noted that the greenhouse experiment was carried out under controlled and limited walk-in cage conditions. Further research under greenhouse conditions and in combination with other potential aphid biocontrol agents will be needed to evaluate their efficacy and feasibility under such applied conditions.

Author contributions

J.P-R: Conceptualization, experimental design, data collection, data analyses and writing—original draft. R.T.V: Data collection. A.L: Conceptualization, experimental design. G.J.M: Conceptualization, experimental design, writing—review and editing.

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Disclosure

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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