Direct Effect of Cannibalism and Intraguild Predation in *Menochilus sexmaculatus* (Coleoptera: Coccinellidae)[1]

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Abstract *Menochilus sexmaculatus* F. (Coleoptera: Coccinellidae) is a generalist predator with potential as a biological control candidate for suppressing many insect pests, including the cotton mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae). However, the potential control capacity of *M. sexmaculatus* on *P. solenopsis* may depend not only on its fitness and predatory efficacy, but also on the consequences of both conspecific and heterospecific interactions with other individuals that share the same resource. This study investigated the aggressiveness and vulnerability of different life stages of *M. sexmaculatus* when encountering various stages of *M. sexmaculatus* or *Harmonia axyridis* (Pallas). The results showed that *M. sexmaculatus* could act as predator and/or prey with the presence of conspecific and heterospecific ladybird beetles. The success of predation is affected by the ladybird beetle life stage and, in most cases, young stages of the ladybird beetles were most susceptible to relatively older life stages of ladybird beetles. Predation between *M. sexmaculatus*/*H. axyridis* larvae of the same developmental stage was always asymmetric, favoring *H. axyridis*. Moreover, *M. sexmaculatus* exhibited intensive aggressiveness toward their own species over heterospecific individuals, but was more vulnerable to *H. axyridis* than to *M. sexmaculatus* individuals. Overall, *H. axyridis* could negatively affect the population densities of *M. sexmaculatus* by its high aggressiveness and low vulnerability. However, because our study was conducted in an oversimplified and confined area, more research should be conducted under more realistic conditions to explore the impacts of *H. axyridis* on the population dynamics of *M. sexmaculatus*.

Key Words *Phenacoccus solenopsis*, *Menochilus sexmaculatus*, *Harmonia axyridis*, cannibalism, intraguild predation

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The cotton mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae), is an insect pest of multiple crops in many countries worldwide (Wang et al. 2020). It can attack at least 213 host plant species within 56 families (Abdulrassoul et al. 2015). *Phenacoccus solenopsis* damages plants directly

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through feeding on any aboveground parts of the plants and indirectly by producing waxy secretions supporting sooty mold growth that hinders photosynthesis (Waqas et al. 2021). Currently, conventional insecticides are the most common and effective method used for suppressing *P. solenopsis* worldwide, but its insecticide resistance and tolerance have increased (Kaur and Virk 2012, Waqas et al. 2021). Therefore, biocontrol agents are being investigated as potential alternatives to control this pest (Zilaei et al. 2022).

Ladybird beetles (Coleoptera: Coccinellidae) are the dominant predator group in controlling populations of *P. solenopsis* in nature (Tong et al. 2019). *Menochilus sexmaculatus* F. (Coleoptera: Coccinellidae) is an omnivorous predator capable of feeding on many insect pests (Ranjbar et al. 2020) and has potential as a biological control candidate against *P. solenopsis* (Waqas et al. 2021). However, similar to other predators, the potential control capacity of *M. sexmaculatus* on *P. solenopsis* may depend not only on its fitness and predatory efficacy, but also on other factors, such as the consequence of both conspecific and heterospecific interactions with other individuals that share the same resource (Abraços Duarte et al. 2021, Burgio et al. 2002).

Conspecific and heterospecific interactions are common and important characteristics of many ladybird beetle species and then may affect the ladybird beetle population dynamics (Agarwala and Dixon 1992, Rasekh and Osawa 2020). Ladybird beetles that use the same habitat and prey are likely to compete with one another for common resources and subsequently inflict death on each other via cannibalism and intraguild predation (IGP) (Burgio et al. 2002, Lucas et al. 1998, Pervez et al. 2021, Ranjbar et al. 2020). Cannibalism can be observed in various life stages of ladybird beetles among conspecific species, including egg, larva, and pupa (Kundoo and Khan 2017, Pervez et al. 2021, Yasuda et al. 2001). Intraguild predation is a type of predation in which predators feed on competitors within a guild (Polis and Holt 1992). These two types of interactions can promote the sustenance of the predator at prey shortage scenarios or in the absence of high-quality prey conditions, or eliminate the interacting species (Momen and Abdel-Khalek 2021, Shakya et al. 2010). The impacts of cannibalism and IGP on ladybird beetle population dynamics are diverse (Agarwala and Dixon 1992, Takizawa and Snyder 2011, Yasuda et al. 2001) and may be influenced by the different vulnerabilities and aggressiveness of ladybird beetles to conspecific and heterospecific species. For example, *Harmonia axyridis* (Pallas) has been shown to be more intensely aggressive toward *H. yedoensis* Takizawa than to conspecific species, whereas *H. yedoensis* shows similar aggressiveness to both conspecific and heterospecific individuals. The intense characteristic in IGP and less so in cannibalism in *H. axyridis* may partly cause it to be the dominated predator of aphidophagous guilds, but a similar intensity in IGP and cannibalism in *H. yedoensis* may limit its population densities (Rasekh and Osawa 2020).

In many crops, *M. sexmaculatus* is known to prey on *P. solenopsis* together with other ladybird beetle species, including *H. axyridis* (Xu et al. 2017). Cannibalism and IGP were frequently observed on *M. sexmaculatus* (Pervez et al. 2021, Ranjbar et al. 2020, Yadav et al. 2019). However, information regarding the occurrence of IGP between *H. axyridis* and *M. sexmaculatus*, and the differences of the aggressiveness or vulnerability of *M. sexmaculatus* to conspecific and heterospecific species are lacking. The aims of this study were to (1) investigate the occurrence of IGP between *M. sexmaculatus* and *H. axyridis*, and (2) compare the aggressiveness or vulnerability of different life stages of *M. sexmaculatus* when encountering all stages of *M. sexmaculatus* or *H. axyridis*.

Materials and Methods

Plants and insects. *Menochilus sexmaculatus* colonies were collected from common bean fields at the Experimental Farm, South China Agricultural University (Guangzhou, Guangdong, China) in August 2021. *Harmonia axyridis* was obtained from a laboratory colony at Qingdao Agricultural University (Qingdao, Shandong, China) in August 2021. Pairs of *M. sexmaculatus* or *H. axyridis* were placed in 3-cm Petri dishes (diameter: 3 cm, height: 1.5 cm) and reared on *P. solenopsis* and *Aphis craccivora* Koch for more than 10 generations. *Phenacoccus solenopsis* was collected from cotton, and *A. craccivora* was obtained from common bean at the Experimental Farm in June 2021. *Phenacoccus solenopsis* and *A. craccivora* were maintained on cotton plants (*Gossypium hirsutum* L., cultivar: Lumianyan no. 32) and broad bean plants (*Vicia faba* L., cultivar: Jinnong), respectively. Ladybird beetle eggs were harvested and individually transferred to new Petri dishes using a fine camel hair brush. Newly hatched larvae were individually placed into a new 3-cm Petri dish and provisioned with an excess of *P. solenopsis* and *A. craccivora* daily until they reached the life stages for all subsequent experiments. All colonies and experiments were maintained in an insectary at 25 ± 1°C and 65 ± 5% relative humidity (RH) under a 16L:8D photoperiod.

Cannibalism and IGP trials. The presence and strength of predation between two *M. sexmaculatus* individuals, or between *M. sexmaculatus* and *H. axyridis*, were examined in 3-cm Petri dishes. Cannibalism trials were conducted using the eggs, four larval instars, pupae, and female adults of *M. sexmaculatus*. Intraguild predation experiments were also evaluated using various life stages of *M. sexmaculatus* and *H. axyridis*. Combinations involving the life stages (egg–egg, egg–pupae, pupae–pupae) that exhibited nonpredatory interactions were not included in the study. Thus, 25 different combinations were tested for the cannibalism trials, and 45 different combinations were conducted for the IGP trials. Each combination was replicated 15 times.

Eggs, larvae, and pupae of both ladybird beetle species used in our experiments were < 24 h old, and the adult females used were 1–2 wk old. Before testing, the ladybird beetles were isolated with a water-saturated cotton ball in a 3-cm Petri dish for 12 h to standardize their hunger level. Then, individuals of *M. sexmaculatus* were confined in a 3-cm Petri dish together with one individual from *M. sexmaculatus* or *H. axyridis* colonies. After 24 h, the Petri dish was checked under a stereo microscope to determine the survival of both ladybird beetles. To assess the natural mortality levels of each ladybird beetle species during a 24-h period, 15 individuals of each ladybird beetle species at different life stages were individually confined in the Petri dish containing a water-saturated cotton ball. In the case of interactions with eggs and pupae, larvae hatching from eggs or adult emergence from pupae that had been exposed to a predator were compared with those of the control treatment to determine the incidence of predation.

Statistical analysis. Statistical analyses were conducted using SPSS (version 21.0; SPSS, Inc., Chicago, IL). Data on the number of individuals consumed in each combination in cannibalism between two *M. sexmaculatus* individuals and IGP between *M. sexmaculatus* and *H. axyridis* were compared using a χ^2 test (two-tailed Fisher's exact test, $P < 0.05$). The same χ^2 test was also used to compare differences between the number of *M. sexmaculatus* consumed by *M. sexmaculatus* and *H. axyridis*, and the number of *M. sexmaculatus* and *H. axyridis* eaten by *M. sexmaculatus*.

Results

Natural mortality in the control treatments was low (from 0 to 6.7%) for all life stages of *M. sexmaculatus* and *H. axyridis*. Since both the eggs and pupae of *M. sexmaculatus* and *H. axyridis* could not exhibit predatory capacity, they were the victims of predation in all combinations. Additionally, when *M. sexmaculatus* adults were paired with four larval instars and adults of *M. sexmaculatus* or *H. axyridis*, no consumption was observed on the ladybird beetle adults.

Cannibalism between *M. sexmaculatus* individuals. In combinations with *M. sexmaculatus* eggs, 86.67%, 93.33%, 93.33%, 100%, and 100% of eggs were consumed by first to fourth instars and adults of *M. sexmaculatus*, respectively. When *M. sexmaculatus* pupae were provided, only 6.67%, 13.33%, and 20% of *M. sexmaculatus* pupae were consumed by the third and fourth instars and adults of *M. sexmaculatus*, respectively. Except for the combination when the fourth instars of *M. sexmaculatus* were paired with *M. sexmaculatus* adults, later stages of *M. sexmaculatus* larvae and adults fed on earlier stages of *M. sexmaculatus* larvae than the reverse (Fisher's exact test: $P < 0.05$ for all). In combination with fourth instars of *M. sexmaculatus*, the number of fourth instars of *M. sexmaculatus* consumed by *M. sexmaculatus* adults was not significantly different than the reverse (Fisher's exact test: $P = 0.100$) (Fig. 1). When two same instar larvae were placed together, cannibalism rates were 40%, 53.33%, 33.33%, and 60% from first to fourth instars, respectively.

IGP between *M. sexmaculatus* and *H. axyridis*. When eggs of *M. sexmaculatus* or *H. axyridis* were provided, both larvae and adults of *H. axyridis* (first instars: 60%; second instars: 60%; third instars: 100%; fourth instars: 93.33%; adults: 93.33%) and *M. sexmaculatus* (larvae: 100%; adults: 100%) acted as intraguild (IG) predators. Only third and fourth instars and adults of *H. axyridis* could feed on *M. sexmaculatus* pupae (third instars: 66.67%; fourth instars: 86.67%; adults: 60%), but *H. axyridis* pupae were not killed by *M. sexmaculatus*. In combinations with first and second instars of *M. sexmaculatus*, *M. sexmaculatus* larvae were more vulnerable to IGP by *H. axyridis* than vice versa in all cases (Fisher's exact test: $P < 0.05$ for all), except for when the second instars of *M. sexmaculatus* were paired with the first instar *H. axyridis* larvae (Fisher's exact test: $P = 0.651$). Third instars of *M. sexmaculatus* fed on more first instars of *H. axyridis* than the reverse (Fisher's exact test: $P < 0.05$), whereas they were more vulnerable to IGP by third and fourth instars and adults of *H. axyridis* than vice versa (Fisher's exact test: $P < 0.05$ for all). The number of third instars of *M. sexmaculatus* and second instars of *H. axyridis* that were consumed by each other did not differ significantly (Fisher's exact test: $P = 0.245$). Fourth instars of *M. sexmaculatus* preyed on more first and second instars of *H. axyridis* than vice versa (Fisher's exact test: $P < 0.05$ for both). Fourth instars of *M. sexmaculatus* were more vulnerable to IGP by fourth instars and adults of *H. axyridis* than the reverse (Fisher's exact test: $P < 0.05$ for both), whereas the number of third instars of *H. axyridis* and fourth instars of *M. sexmaculatus* consumed by each other was not significantly

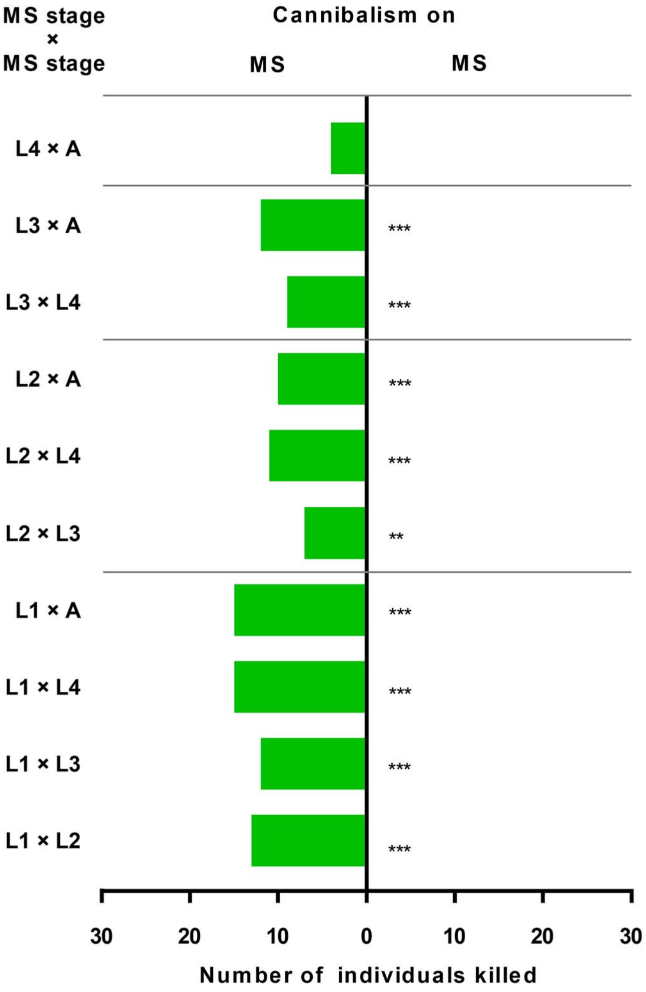

Fig. 1. Cannibalism between various life stages of *Menochilus sexmaculatus*. The green bars represent the total numbers of *M. sexmaculatus* consumed. L1 = first instar larva, L2 = second instar larva, L3 = third instar larva, L4 = fourth instar larva, and A = adult; MS = *Menochilus sexmaculatus*. Asterisks indicate significant differences for that combination of ladybirds (*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$).

different (Fisher's exact test: $P = 0.700$). *Menochilus sexmaculatus* adults fed on more first and second instars of *H. axyridis* than vice versa (Fisher's exact test: $P < 0.05$ for both). However, the number of third or fourth instars of *H. axyridis* and adults of *M. sexmaculatus* consumed by each other was not significantly different (Fisher's exact test: $P > 0.05$ for both) (Fig. 2).

***Menochilus sexmaculatus* as a predator..** First instars of *M. sexmaculatus* could not prey on second, third, and fourth instars, and pupae of *M. sexmaculatus*

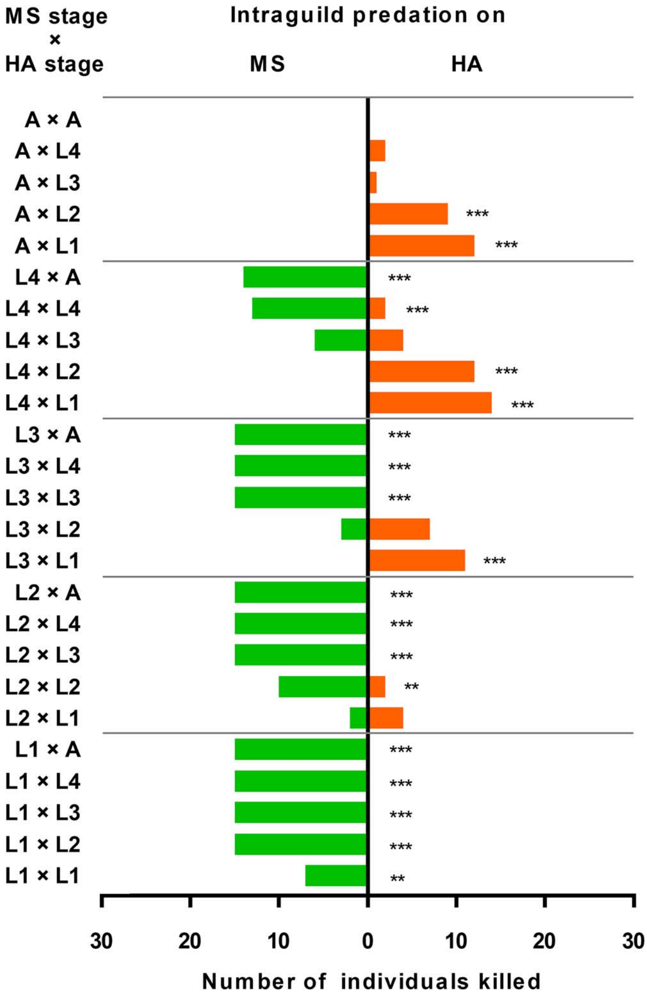

Fig. 2. Intraguild predation between various life stages of *Menochilus sexmaculatus* (green bars) and *Harmonia axyridis* (orange bars). L1 = first instar larva, L2 = second instar larva, L3 = third instar larva, L4 = fourth instar larva, and A = adult; MS = *Menochilus sexmaculatus*, and HA = *Harmonia axyridis*. Asterisks indicate significant differences for that combination of ladybirds (*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$).

and *H. axyridis*. First instars of *M. sexmaculatus* consumed significantly more first instars of *M. sexmaculatus* than first instar *H. axyridis* larvae (Fisher's exact test: $P = 0.017$), but no significant differences were observed between eggs of *M. sexmaculatus* and *H. axyridis* (Fisher's exact test: $P = 0.215$). In combination with second instars of *M. sexmaculatus*, none of the third and fourth instars, and pupae were the victims of predation. Second instars of *M. sexmaculatus* consumed significantly more first instars of *M. sexmaculatus* than first-instar *H. axyridis* larvae (Fisher's exact test:

$P = 0.003$); no significant differences were observed between eggs or second instars of *M. sexmaculatus* and *H. axyridis* (Fisher's exact test: $P > 0.05$ for both). When paired with a conspecific third instar larva or a heterospecific third instar larva together, third instars of *M. sexmaculatus* killed more conspecific larvae (Fisher's exact test: $P = 0.042$). However, there were no differences in the feeding events between eggs, first instars, second instars, or pupae of *M. sexmaculatus* and *H. axyridis* (Fisher's exact test: $P > 0.05$ for all). Additionally, third instars of *M. sexmaculatus* could not consume the fourth instars of *M. sexmaculatus* and *H. axyridis*. Fourth instars of *M. sexmaculatus* consumed significantly more fourth instars of *M. sexmaculatus* than fourth instar *H. axyridis* larvae (Fisher's exact test: $P = 0.021$), but no significant differences were found between eggs, first instars, second instars, third instars, or pupae of *M. sexmaculatus* and *H. axyridis* (Fisher's exact test: $P > 0.05$ for all). When paired with *M. sexmaculatus* adults, a higher number of predation events on third instars of *M. sexmaculatus* was observed than on third instar *H. axyridis* larvae (Fisher's exact test: $P < 0.001$). However, no significant differences were observed between eggs, first instars, second instars, fourth instars, or pupae of *M. sexmaculatus* and *H. axyridis* (Fisher's exact test: $P > 0.05$ for all) (Fig. 3).

***Menochilus sexmaculatus* as prey.** For eggs and first instars of *M. sexmaculatus*, no statistical differences were found in the number of *M. sexmaculatus* consumed between individuals of the same developmental stage of *M. sexmaculatus* and *H. axyridis* (Fisher's exact test: $P > 0.05$ for all). With second instars of *M. sexmaculatus*, the number of *M. sexmaculatus* larvae consumed by third instars and adults of *H. axyridis* was significantly higher than those by third instars and adults of *M. sexmaculatus* (Fisher's exact test: $P < 0.05$ for both). However, there were no significant differences in the feeding events on *M. sexmaculatus* between the first, second, or fourth instars of *M. sexmaculatus* and *H. axyridis* (Fisher's exact test: $P > 0.05$ for all). Third instars of *M. sexmaculatus* could not be consumed by the first instars of *M. sexmaculatus* and *H. axyridis*. The number of third-instar *M. sexmaculatus* larvae consumed by third and fourth instars of *H. axyridis* was significantly higher than those by third and fourth instars of *M. sexmaculatus* (Fisher's exact test: $P < 0.05$ for both). Nevertheless, no significant differences were found in feeding events on *M. sexmaculatus* between second instars or adults of *M. sexmaculatus* and *H. axyridis* (Fisher's exact test: $P > 0.05$ for both). Neither of the first and second instars of *M. sexmaculatus* and *H. axyridis* could feed on the fourth instars of *M. sexmaculatus*. The number of *M. sexmaculatus* larvae consumed by third instars and adults of *H. axyridis* was significantly higher than those by third instars and adults of *M. sexmaculatus* (Fisher's exact test: $P < 0.05$ for both). However, when paired with a conspecific fourth-instar larva or a heterospecific fourth-instar larva together, there were no significant differences in the feeding events on fourth instars of *M. sexmaculatus* between these two species (Fisher's exact test: $P = 0.215$). Neither of the first and second instars of *M. sexmaculatus* and *H. axyridis* could consume *M. sexmaculatus* pupae. The number of *M. sexmaculatus* pupae consumed by third and fourth instars of *H. axyridis* was significantly higher than those by third and fourth instars of *M. sexmaculatus* (Fisher's exact test: $P < 0.05$ for both). However, no statistical differences were found in the feeding events on *M. sexmaculatus* pupae between adults of *M. sexmaculatus* and *H. axyridis* (Fisher's exact test: $P = 0.060$) (Fig. 4).

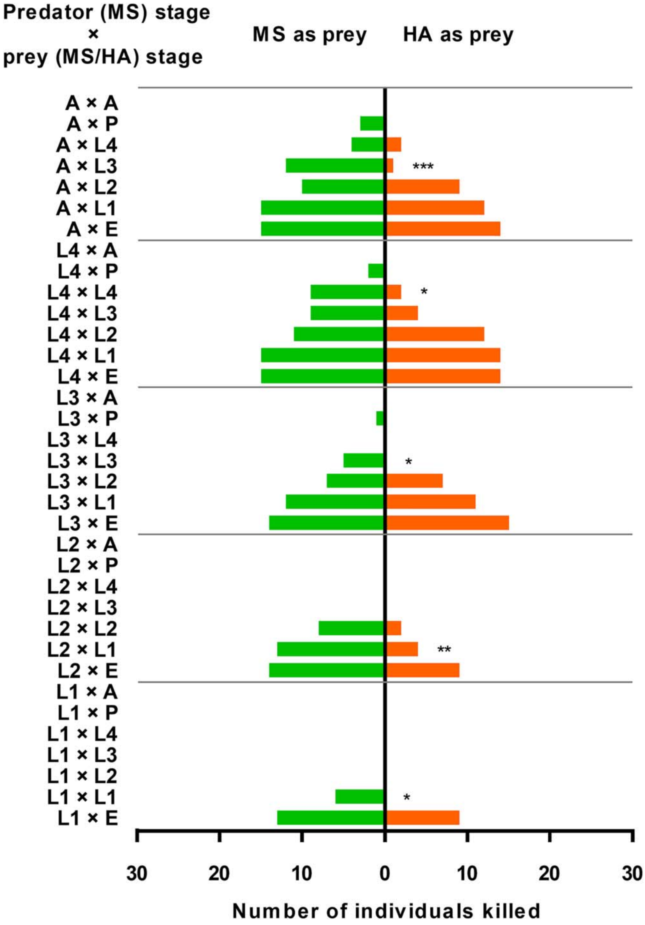

Fig. 3. Total number of *Menochilus sexmaculatus* (green bars) and *Harmonia axyridis* (orange bars) at various life stages consumed by four larval instars and adults of *M. sexmaculatus*. E = egg, L1 = first instar larva, L2 = second instar larva, L3 = third instar larva, L4 = fourth instar larva, P = pupa, and A = adult; MS = *Menochilus sexmaculatus*, and HA = *Harmonia axyridis*. Asterisks indicate significant differences between values of *M. sexmaculatus* and *H. axyridis* (*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$).

Discussion

Our results demonstrated that *M. sexmaculatus* could feed on conspecific individuals and was the IG predator and/or intraguild prey (IG prey) in confrontations with *H. axyridis*. Success of cannibalism and IGP was stage dependent: young stages of ladybird beetles were the most susceptible to predation, and relatively older larvae and adults of ladybird beetles were likely to be predators in most

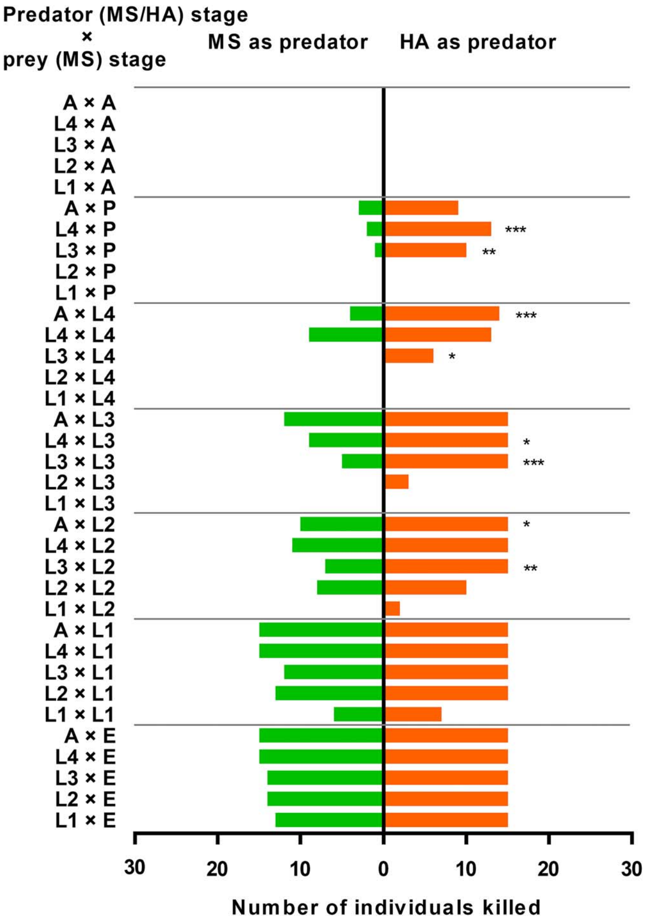

Fig. 4. Total number of *Menochilus sexmaculatus* at various life stages consumed by four larval instars and adults of *M. sexmaculatus* (green bars) and *Harmonia axyridis* (orange bars). E = egg, L1 = first instar larva, L2 = second instar larva, L3 = third instar larva, L4 = fourth instar larva, P = pupa, and A = adult; MS = *Menochilus sexmaculatus*, and HA = *Harmonia axyridis*. Asterisks indicate significant differences between values of *M. sexmaculatus* and *H. axyridis* (*, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$).

cases. In the IGP assays with the same instar larvae, *H. axyridis* were always victorious compared to *M. sexmaculatus*. Additionally, *M. sexmaculatus* intensively killed the conspecific individuals over heterospecific competitors, whereas they were more vulnerable to heterospecific individuals than to conspecific ladybird beetles.

In the present study, *M. sexmaculatus* could act as predator and/or prey when confronted with conspecific and heterospecific ladybird beetle individuals, which is consistent with previous studies (Pervez et al. 2021, Ranjbar et al. 2020). In addition, the early life stages of *M. sexmaculatus* and *H. axyridis*, which are the smaller-sized individuals, were vulnerable to cannibalism and IGP. Generally, cannibalism and IGP between predators are affected by the body size of species, in which the smaller individuals are consumed by larger ones (Abraços Duarte et al. 2021, Lucas et al. 1998, Rasekh and Osawa 2020). However, larger individuals did not possess an absolute advantage in all combinations investigated in the study. When the size of *M. sexmaculatus* larvae were larger than those of the *H. axyridis* with which they were paired (*M. sexmaculatus* × *H. axyridis*: second instars × first instars, third instars × second instars, fourth instars × third instars), they acted as both the IG predator and IG prey. Moreover, in confrontations with the same instar larvae, *H. axyridis* was always victorious. The superiority of *H. axyridis* could be attributed to its greater aggressiveness toward heterospecific species (Katsanis et al. 2013, Rasekh and Osawa 2020, Yasuda et al. 2001). In addition, because the defensive chemical compounds in the hemolymph and reflex fluid of *H. axyridis* larvae are repulsive or toxic to many ladybird beetle species, this may be the way in which *H. axyridis* avoids IGP by other ladybird beetle species (Cottrell 2004, Pell et al. 2008). In our experiment, the species-specific chemical protection may help *H. axyridis* against *M. sexmaculatus*. Nevertheless, adults of *H. axyridis* and *M. sexmaculatus* were not preyed upon by the other ladybird beetle individuals. Body sclerotization of ladybird beetle adults may be a reason for low predation on this prey type, as predators of aphids have an obvious preference for soft-bodied insects (De Clercq et al. 2003). Moreover, because eggs and pupae cannot exhibit escape behavior, they are only the victims of predation. Similar results were observed in other studies reporting cannibalism and IGP could be affected by the mobility of predators (Lucas et al. 1998, Pervez et al. 2021).

Generally, the incidence of cannibalism or IGP of ladybird beetles increases when the relative abundance of shared prey to ladybird beetle is low or in the absence of high-quality prey scenarios (Agarwala and Dixon 1992, Kundoo and Khan 2017, Ranjbar et al. 2020, Sato et al. 2003). The conspecific and heterospecific predators can act as an alternative prey source to the organism under these unfavorable conditions (Agarwala and Dixon 1992). However, this is not always beneficial when the prey are full siblings (Osawa 1992), or the heterospecific ladybird beetles are toxic (Agarwala and Dixon 1992, Sato and Dixon 2004). Many studies have shown that *H. axyridis* is unsuitable prey for multiple ladybird beetle species (Cottrell 2004, Katsanis et al. 2013, Rasekh and Osawa 2020). In the present experiments, the intensity of predation on *M. sexmaculatus* was higher than that on *H. axyridis* when *M. sexmaculatus* was the predator. In the scarce prey conditions or without high-quality prey scenarios, *M. sexmaculatus* may have to concentrate on consuming conspecific ladybirds to ensure its survival and be reluctant to consume *H. axyridis*. This intense characteristic in cannibalism and less so in IGP in *M. sexmaculatus* may negatively affect its population densities. In addition, by comparing the predation incidence between IGP by *H. axyridis* and cannibalism by *M. sexmaculatus*, we found that *M. sexmaculatus* was highly susceptible to predation by *H. axyridis*. The greater aggressiveness of *H. axyridis* toward *M. sexmaculatus* may further reduce the population densities of *M. sexmaculatus* when food resource conditions are unfavorable. Consequently, *H. axyridis* may restrict the population densities of *M. sexmaculatus* by its high aggressiveness and low vulnerability, which may influence the population establishment and subsequent application of *M. sexmaculatus* in biological control programs.

However, we must note that this study was conducted in an oversimplified, confined area. In the field, many factors may decrease the encounter rate between different predators and reduce the intensity of cannibalism and IGP, such as the density of prey resources (Abraços Duarte et al. 2021, Burgio et al. 2002, Lucas et al. 1998), habitat structure (Janssen et al. 2007, Sun et al. 2021), and emigration time (Sato et al. 2003). Thus, our laboratory studies may overestimate the effects of cannibalism and IGP on *M. sexmaculatus* under natural conditions. Despite this, simplified laboratory-based trials remain essential for depicting the interspecific relationship between *M. sexmaculatus* and *H. axyridis* and investigating the potential impacts of cannibalism and IGP on *M. sexmaculatus*.

In conclusion, *M. sexmaculatus* could prey on conspecific individuals and acted as an IG predator and/or IG prey when confronted with *H. axyridis*. Moreover, *M. sexmaculatus* was more intensely aggressive toward conspecific individuals and less so to heterospecific ladybirds, but was more susceptible to *H. axyridis* than to *M. sexmaculatus*. It is likely that the establishment of *M. sexmaculatus* populations will be negatively affected due to the presence of *H. axyridis*, which may hinder the success of biological control programs in the management of *P. solenopsis* populations in crops. Given the limitations of our laboratory setting, further research should be conducted under more realistic conditions in the field and semi-field levels to understand how species interactions may influence the short- and long-term population dynamics of *M. sexmaculatus* and what measures may effectively contribute to conserving the populations of *M. sexmaculatus*.

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