BIODIVERSITAS
Volume 26, Number 8, August 2025
Pages: 4057-4064

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d260835

Field-laboratory assessment of predatory response of *Chilocorus melanophthalmus* and *Scymnus* sp. against *Aulacaspis tegalensis* (Hemiptera: Diaspididae) infestation on sugarcane

SUDI PRAMONO
Department of Plant Protection, Agriculture Faculty, Universitas Lampung. Jl. Prof. Sumantri Brojonegoro No. 1, Bandar Lampung 35145, Lampung, Indonesia. Tel./fax.: +62-721-701609, email: sudi.pramono@fp.unila.ac.id

Manuscript received: 25 April 2025. Revision accepted: 22 August 2025.

Abstract. *Pramono S. 2025. Field-laboratory assessment of predatory response of* Chilocorus melanophthalmus *and* Scymnus *sp. against* Aulacaspis tegalensis *(Hemiptera: Diaspididae) infestation on sugarcane. Biodiversitas 26: 4057-4064.* Sugarcane production in Indonesia is significantly affected by pest infestations, among which the sugarcane scale insect (*Aulacaspis tegalensis*) is particularly destructive due to its ability to reduce both crop yield and quality. This study aimed to evaluate the potential of natural enemies as biological control agents for *A. tegalensis* to provide a more sustainable alternative. Field and laboratory experiments were conducted from April 2021 to September 2022 in sugarcane plantations in Central Lampung, Lampung, Indonesia. Field experiments, arranged in a randomized block design, monitored predator-prey interactions and measured predator attack rates on *A. tegalensis*. Laboratory experiments, using a completely randomized design, evaluated predation at prey densities of 10-320 individuals with two predator species, *Chilocorus melanophthalmus* and *Scymnus* spp.. The results showed that *C. melanophthalmus* and *Scymnus* spp. had moderate positive correlations with *A. tegalensis* population densities in the field (correlation coefficients r: 0.51 and 0.41, respectively; $p<0.05$). Their average predation rate for *C. melanophthalmus* was 4-10 prey individuals per day, and for *Scymnus* spp. 4-9 prey individuals per day that which are indeed promising biological control agents. Laboratory tests indicated that these two predators exhibited a type II functional response, meaning that their predation rate increased with prey density but eventually reached a saturation point due to handling time constraints. Both predators showed strong dependency on prey density (r: 0.73 and 0.82), indicating high predation potential. Conversely, *C. nigritus* and *Telsimia* spp. showed weaker responses and limited predation efficiency. These findings suggest that *C. melanophthalmus* and *Scymnus* spp. are promising biological control agents for managing *A. tegalensis* infestations in sugarcane plantations, instilling confidence in the future of sustainable pest management. Integrating these predators into integrated pest management strategies could reduce reliance on chemical insecticides, lowering environmental risks and supporting sustainable sugarcane production in Indonesia.

Keywords: Biological control, *Chilocorus melanophthalmus*, predator-prey interaction, *Scymnus* sp., sugarcane scale insect

INTRODUCTION

The plantation subsector significantly contributes to Indonesia's economy, with plantation exports valued at 33.79 billion USD in 2023 (Syah 2024). This highlights the growing importance of plantations to the national economy and their potential to support sustainable development. Despite sugarcane being cultivated on 504,800 ha and national production reaching 2.4 million tons in 2024, the sugarcane industry contributes little to export figures (Syah 2024). Sugarcane productivity remains low, averaging 67.3 tons/ha, with sugar content declining from 7.89% (Hussain et al. 2018) to 7% in 2023 (Syah 2024). Contributing factors include sugarcane variety, soil fertility, rainfall patterns, and pest and disease outbreaks (Hussain et al. 2018; Watson 2021; Mehdi et al. 2024; Efri et al. 2025).

Among the major pests, the sugarcane scale insect (*Aulacaspis tegalensis*) (Hemiptera: Diaspididae) has emerged as a key threat. In sugarcane plantations in Central Lampung, Indonesia, infestations have spread across 18% of the area (Pramono et al. 2020, 2025). This pest affects all varieties and causes varying levels of damage. Monoculture practices and year-round crop availability likely support its persistence. Chemical control is ineffective, as the insect hides under leaf sheaths, which also aid its reproduction (Egonyu et al. 2022).

The intensity of *A. tegalensis* infestations has risen over the years, affecting all sugarcane varieties and resulting in damage that ranges from mild to severe. Synder (2019) and Trisnawati et al. (2022) noted that monoculture farming practices tend to reduce biodiversity, destabilize ecosystems, and foster pest outbreaks. The annual availability of sugarcane crops at various growth stages in sugarcane plantations is believed to contribute to the persistence of this pest (Raut et al. 2024). Chemical control methods have proven largely ineffective because the insects tend to reside beneath leaf sheaths on sugarcane stems, and unstripped leaf sheaths further promote the reproduction and spread of *A. tegalensis* (Pramono et al. 2020, 2025).

The scale insects that attack sugarcane have been identified as *A. tegalensis* (Pramono et al. 2020, 2025; Sarjan et al. 2021; Watson 2021). Since the early 2000s, this pest has escalated from being a minor threat to a major threat (Pramono et al. 2018; Kumar et al. 2024; Bhowmik and Yadav 2025), with infestations reaching up to 18% of the plantation area (Sarjan et al. 2021). Once considered a relatively insignificant pest, *A. tegalensis* became the primary pest between 2002 and 2007, surpassing the damage caused by top and stem borers in Sugar Group Company plantations. Infestation levels reached 58.34% in 4-month-old plants and 63.34% in 6-month-old plants (Kumar et al. 2024). By July 2012, up to 66.44% of sugarcane stalks had been infested, indicating a near-universal distribution within the sugarcane plantation in Lampung.

Environmental factors such as wind and ant activity play a crucial role in the spread of this pest (Mishra et al. 2023). Ants are particularly important vectors because only the first-instar nymphs of *A. tegalensis* are mobile; in later developmental stages, they become immobile (Watson 2021). Understanding its ecology and dispersal mechanisms is therefore essential for effective management (Mokotjomela et al. 2016; Alzate and Onstein 2022). Pest populations typically follow these spatial patterns: random, regular, or aggregated (Pramono et al. 2020; Ahmad-Abadi et al. 2022). In the case of *A. tegalensis*, a regular distribution occurs at low densities, shifting to aggregated patterns as the host plants mature and the population increases (Affandi et al. 2019; Pramono et al. 2020, 2025).

Although natural enemies, such as predators and parasitoids, exist in sugarcane plantations, their effectiveness against *A. tegalensis* has not been well demonstrated. Natural predators include species from the genera *Chilocorus*, *Telsimia*, and *Scymnus* (Sarjan et al. 2021). However, the potential use of these natural enemies as biological control agents remains underexplored, warranting further investigation and evaluation. Recent studies have demonstrated the promising biological control potential of indigenous predatory beetles and coccinellids against *A. tegalensis* (Kumar et al. 2017; Singh et al. 2023), highlighting the importance of conservation biological control approaches to enhance predator populations in sugarcane ecosystems. Based on field observation in Central Lampung, only two species, *Chilocorus melanophthalmus* and *Scymnus* spp. showed moderate field dependency on pest density, suggesting their potential as a key biological control agent. Despite this, there is still limited information on the functional response and predatory efficiency of these dominant predators under controlled conditions. Predator-prey dependency is vital for assessing biological control potential. As prey density increases, predator abundance and diversity tend to rise. Predator responses to prey density are categorized into functional and numerical responses (Pramono et al. 2020, 2025). Functional responses refer to the amount of prey consumed by a predator at different prey densities. In contrast, numerical responses are related to changes in predator population in response to prey densities. These metrics are crucial in understanding predator roles in pest regulation. Functional response studies on sugarcane predator species such as *Chilocorus* spp. And *Telsimia* spp. Have revealed type II and III responses, which indicate effective predation at variable prey densities (Pehlivan et al. 2020; Papanikolaou et al. 2021). Understanding these functional responses aids in optimizing biological control strategies and predator augmentation programs.

This study aimed to investigate the relationship between *A. tegalensis* and its predators in sugarcane fields, with a specific focus on the functional role of the predator *C. melanophthalmus* and *Scymnus* spp. to varying pest densities, and to examine population dynamics across different sugarcane growth stages.

MATERIALS AND METHODS

Study area

This research was carried out from April 2021 to September 2022 in the sugarcane plantations in Gunung Batin, Central Lampung, Indonesia. Field observations were conducted in commercial sugarcane plantations, and laboratory analyses were performed at the entomology laboratory of sugarcane plantation. The region experiences a tropical climate with average daily temperatures ranging from 27 to 32°C and moderate rainfall.

Field experimental design and sampling

A randomized complete block design with four replications was used for the field trials. The main treatment factor was the age of sugarcane plants at different growth stages. Each experimental plot covered approximately 11 to 12.5 ha. Sampling was conducted biweekly starting from four months of plant age until harvest at 12 months.

Within each plot, 45 sugarcane plants were selected based on uniform morphological characteristics. Sampling points were randomly selected along the rows, with a total of 17 observations per block per sampling event. Data collected included counts of predators and *A. tegalensis* on sugarcane stalks, leaf sheaths, and leaves. Scale insect populations were assessed after removal of leaf sheaths by counting individuals along the internodes from the base to the apex.

Data from the field were analyzed using multiple linear regression models to evaluate the relationship between predator abundance and pest density over time and across growth stages. Statistical assumptions, such as normality and homoscedasticity, were checked prior to analysis.

Laboratory feeding assay

Functional response experiments were conducted under controlled laboratory conditions with temperatures ranging from 24 to 34°C. Transparent Petri dishes (9 cm diameter) served as arenas. Prey consisted of sugarcane internodes naturally infested with *A. tegalensis* at six density levels: 10, 20, 40, 80, 160, and 320 individuals. A single adult female predator, *C. melanophthalmus* or *Scymnus* spp., was introduced into each dish. To control the hunger level and standardize predator motivation, all predators were starved for 24 hours prior to the experiment. Each prey density treatment was replicated five times per predator species, resulting in 60 experimental units (6 prey densities × 5 replicates × 2 predator species). Predation was recorded by counting the number of preys consumed after 24 hours of exposure. Observations continued daily until predator mortality to evaluate feeding behavior and adaptation to prey densities.

Data analysis

Functional response data were analyzed using logistic regression models following Darbalaei et al. (2022) to determine the type of functional response (type II or III). The logistic regression tested the proportion of prey consumed relative to prey density, and the sign and significance of the linear and quadratic terms guided classification of the response type. Handling time (Th) and attack rate (a) parameters were estimated by fitting Holling's disc equation (Pulley et al. 2020) using nonlinear least squares regression. Statistical analyses were performed using SPSS version 22.0 and R software (version 4.2.0). Significance levels were set at α: 0.05.

RESULTS AND DISCUSSION

Population dynamics of scale insects and the predators

Scale insects were predominantly found to infest the sugarcane stalk, especially near the internodal regions. Under conditions of high population density, infestations extended to the leaf sheaths and blades. The mode of damage involved sap extraction from the internodal tissue, which impairs plant growth, reduces stalk diameter, and causes discoloration of the stalk, often resulting in a blackish appearance. This pest is known to have a broad host range, affecting various plant species in tropical and subtropical regions. In Indonesia, scale insects are particularly prevalent in lowlands and dry areas. Infestations by this pest have been reported to cause significant yield losses, ranging from 60 to 100% (Pramono et al. 2020).

Based on the observation results, scale insect and predator populations were present at every sugarcane age (Table 1). Initial observations of scale insects occurred when sugarcane plants reached six months of age, with a relatively low mean population density of 0.37 individuals per stalk. The population showed a continuous and significant increase, reaching a peak average of 2,678.42 individuals per stalk at 10.5 months. Subsequently, a declining trend was observed toward the harvest period, with average densities ranging between 1,530.12 and 1,877.08 individuals per stalk.

The predator *Telsimia* spp. was first detected when sugarcane plants were 6.5 months old, with an average population of 0.19 individuals per stalk. However, the population growth of *Telsimia* spp. was relatively slow and peaked at only 1.28 individuals per stalk. The presence of this predator was not consistent throughout the observation period and was no longer detected by the time the crop reached 11 months of age.

Another predator, *Scymnus* spp., emerged at eight months of plant age, with an initial population density of only 0.01 individuals per stalk. The population gradually increased and peaked at an average of 1.27 individuals per stalk by 10.5 months. Compared with *Telsimia* spp., *Scymnus* spp. has a larger body size, which likely contributes to its greater predation capacity. Notably, *Scymnus* spp. were consistently observed until the end of the growing season.

The predators *C. melanophthalmus* and *C. nigritus* appeared simultaneously when the sugarcane plants were 8.5 months old, with initial population densities of 0.03 and 0.02 individuals per stalk, respectively. Both species showed population growth, albeit at different rates, and peaked at 10.5 months with average populations of 1.44 and 1.13 individuals per stalk, respectively. Following this peak, their populations declined as the plants approached maturity and harvest.

Table 1. Population of scale insects and several predator species (individuals/stalk)

Sugarcane age (months)	*Aulacapsis tegalensis*	*Chilorus melanophthalmus*	*Scymnus* spp.	*Chilorus nigritus*	*Telsimia* spp.
4	0	0	0	0	0
4.5	0	0	0	0	0
5	0	0	0	0	0
5.5	0	0	0	0	0
6	0.37	0	0	0	0
6.5	22.95	0	0	0	0.19
7	348.34	0	0	0	0.11
7.5	368.89	0	0	0	0.18
8.0	371.12	0	0.01	0	0.12
8.5	1,394.57	0.03	0.03	0.02	0.06
9	2,677.32	0	0	0	0.07
9.5	1,427.94	0.06	0.06	0.06	0.10
10	1,515.69	0.73	1.21	1.07	1.28
10.5	2,678.42	1.44	1.27	1.13	0.84
11	1,877.08	0.36	0.42	0.02	0
11.5	1,530.12	0.40	0.05	0	0
12	1,877.08	0.36	0.02	0	0

These findings indicate that although several predator species are naturally associated with scale insect infestations in sugarcane, their population densities are generally low and often not synchronous with peak pest populations (Costamagna et al. 2015). This suggests a limited potential for effective natural control, highlighting the need for integrated pest management strategies that incorporate both biological and cultural control methods.

Table 2 shows the relationship between the *A. tegalensis* populations and four predator species. *C. melanophthalmus* and *Scymnus* spp. exhibited moderate positive correlations with scale insect density, with correlation coefficients (r) of 0.51 and 0.41, respectively, both of which showed statistically significant P-values (<0.0001). *Chilocorus melanophthalmus* had the highest coefficient of determination (R^2: 0.26), indicating that it explained 26.1% of the variation in predator populations relative to the scale insect density. *Chilocorus nigritus* and *Telsimia* spp. showed weaker, mild correlations with *A. tegalensis*, with r-values of 0.34 and 0.38, respectively, and lower R^2 values (0.12 and 0.15). Despite all relationships being statistically significant, the strength of the association varied, suggesting that *C. melanophthalmus* and *Scymnus* spp. may have greater potential as natural enemies in biological control efforts.

Predator-prey dynamics and potential for biological control of scale insects in sugarcane

By 11.5 months of plant age, the predator *C. nigritus* was no longer observed in the sugarcane fields. The remaining predators that persisted until immediately before harvest were *C. melanophthalmus* and *Scymnus* spp., although their population densities remained relatively low. The limited abundance of these predators was insufficient to suppress the population of *A. tegalensis*, which led to noticeable crop damage, including the desiccation and wilting of sugarcane plants. Symptoms of plant stress were first recorded at 8.5 months, with early signs of plant mortality evident by 10 months of age.

Among the four predator species identified in this study, namely *C. melanophthalmus*, *Scymnus* spp., *C. nigritus*, and *Telsimia* spp., only *C. melanophthalmus* and *Scymnus* spp., demonstrated a moderate dependency on *A. tegalensis*, with correlation coefficients of 0.51 and 0.41, respectively. These findings suggest that both species have a strong potential as natural enemies for the biological control of scale insects in sugarcane. In contrast, *C. nigritus* and *Telsimia* spp., exhibited weaker dependencies, with correlation values of 0.34 and 0.38, respectively.

Linear regression analyses revealed statistically significant relationships between predator and prey populations. For *C. melanophthalmus*, the regression model was [Y = -0.017+0.039X, P<0.0001]. For *Scymnus* spp., it was [Y = -0.015+0.033X, P<0.0001], where X represents the log-transformed insect population (log[n+1]) and Y denotes the log-transformed predator population (log[n+1]) (Table 2). These significant models reinforce the classification of both *C. melanophthalmus* and *Scymnus* spp. as predators with moderate dependency on *A. tegalensis*, supporting their role as prospective biological control agents.

A notable ecological advantage of moderate-dependency predators is their ability to survive in the field, even when the primary prey is scarce (Hong et al. 2023). These predators may temporarily feed on alternative prey, such as aphids (*Aphis* spp.), woolly aphids (*Ceratovacuna lanigera*), and other small phytophagous insects associated with sugarcane (Pramono et al. 2020, 2025). When the population of scale insect rebounds, these predators can redirect their feeding activity toward the primary pest.

Despite the presence of all four predator species, their collective population densities, ranging from only 0.06 to 1.44 individuals per stalk, were markedly insufficient to control the scale insect population, which peaked at an average of 2,678 individuals per stalk. This stark disparity underscores the need for proactive management strategies, including predator conservation and augmentation, throughout the cropping cycle up to harvest (12 months).

The order of predator appearance was as follows: *Telsimia* spp., was the earliest to emerge at 6.5 months, although it maintained a low density of 0.06-1.28 individuals per stalk. *Scymnus* spp. appeared at 8 months, followed by both *C. melanophthalmus* and *C. nigritus* at 8.5 months. However, the population sizes of *C. melanophthalmus* and *C. nigritus* remained relatively low, with the highest recorded density of *C. melanophthalmus* reaching only 1.44 individuals per stalk at 10.5 months. Although these densities were insufficient to curb the outbreak, proper conservation measures could enhance their efficacy as biological control agents.

Table 2. Relationship between scale insects (*Aulacaspis tegalensis*) and predators

Predators	Y = a+bX	R^2	r	P-value	Dependency*
Chilocorus melanophtalmus	y = -0.017+0.039 x	0.26	0.51	<0.0001	Moderate
Scymnus sp.	y = -0.015+0.033x	0.17	0.41	<0.0001	Moderate
Chilocorus nigritus	y = -0.011+0.025x	0.12	0.34	<0.0001	Mild
Telsimia sp.	y = 0.001+0.026x	0.15	0.38	<0.0001	Mild

Note: Correlation Coefficient (r) interpretation. <0.20: No dependency, 0.21-0.40: Mild dependency, 0.41-0.70: Moderate dependency, 0.71-0.90: Strong dependency, >0.90: Very strong dependency, *: Source from Wagiman (1996)

Among the observed species, *C. melanophthalmus* and *Scymnus* spp. emerged as the most promising candidates for further development. Their consistent presence from around 8 to 8.5 months through to the harvest period, coupled with their moderate dependency on the target pest, supports their candidacy for biological control initiatives. In contrast, *C. nigritus* and *Telsimia* spp. were less reliable due to their weaker dependency and sporadic occurrence. Further candidate selection was based on the field population density throughout the season. *C. melanophthalmus* maintained an average density of 0.26 individuals per stalk from 6 to 12 months, whereas *Scymnus* spp. maintained a slightly lower average of 0.23 individuals per stalk.

Following these field observations, both *C. melanophthalmus* and *Scymnus* spp. were reared under laboratory conditions using *A. tegalensis* as prey. Both species were successfully propagated and maintained under these conditions. The successful establishment of laboratory colonies enabled subsequent experiments on their functional responses to prey density, the results of which are presented in Figures 1 and 2.

The results of the functional response analysis of *C. melanophthalmus* and *Scymnus* spp. to *A. tegalensis* demonstrated that the predation rate increased with the availability of prey (Figure 1). However, beyond a certain prey density, the rate of predation plateaued and eventually declined. *C. melanophthalmus* typically consumed 4-10 while *Scymnus* spp. consumed 4-9 individual *A. tegalensis* per day, and this number tended to remain. This decrease in predation was likely due to predator satiation, whereby the predator reached its feeding capacity and could not consume any additional prey. Both *C. melanophthalmus* and *Scymnus* spp. exhibited a Type II functional response, as classified by New (1991), toward *A. tegalensis*. As a biological control agent, this predator shows considerable potential due to its ability to respond dynamically to fluctuations in prey density.

Predator-prey dependency is a critical trait in evaluating the suitability of biological control agents, as the presence of prey in a particular habitat can attract predators and encourage their colonization and persistence in that area. According to New (1991), there are four types of predator-prey functional responses: Type I (linear), where predation increases or decreases proportionally to prey abundance; Type II (parabolic), where predation rises with prey density up to a threshold, after which it becomes constant or declines; Type III (sigmoidal), where predation begins slowly, then increases rapidly, and finally stabilizes; and Type IV (negative), where predation decreases when prey density becomes excessively high.

Assessing functional responses under laboratory conditions provides important insights into the predation potential of a given species in the field. This assessment helps to determine whether a predator exhibits prey dependency. Moreover, the degree of dependency is also a crucial factor: a strong dependency indicates a tendency toward obligate predation on the primary prey species. In contrast, predators with weak dependency are generally considered less suitable as biological control agents (Coblentz and Delong 2020).

In this experiment, the number of *A. tegalensis* individuals consumed by a single female *C. melanophthalmus* and *Scymnus* pp. conformed to a Type II functional response pattern (Figure 1). This indicates a relationship between prey density and the number of prey items consumed by a predator, where the rate of prey consumption by the predator increases with increasing prey density, but then reaches an asymptote or peak (Premawaardhane and Ueno 2024). This response type is characterized by an increase in the number of prey items consumed with rising prey density, despite a decrease in the predation rate that eventually levels off. The degree of dependence was quantified using the polynomial regression correlation coefficient (r) between prey availability and consumption (0.73). According to Pramono et al. (2020), an r value greater than 0.71 indicates a "strong dependency" between the predator and its prey.

At a low prey density (10 individuals), *C. melanophthalmus* consumed an average of 3.77, while *Scymnus* spp. 3.25 individuals per day. The predation rate increased with prey density, peaking at 160 prey individuals. Beyond this point, additional increases in prey density did not result in higher predation rates, but instead showed a declining trend. This phenomenon is likely due to overpopulation, which reduces the overall freshness and quality of the prey as a result of environmental limitations (e.g., space, food availability, and air circulation). Consequently, this predator reaches its physiological limit (capture, consume, and digest each prey item), constraining the total number of preys that can be consumed. The combination of reduced prey quality and the limitation imposed by handling time leads to an overall decline in feeding efficiency.

When compared with *C. melanophthalmus*, no significant difference was observed in predation behavior. In conclusion, the dependency of *C. melanophthalmus* and *Scymnus* spp. on *A. tegalensis* under field conditions was categorized as moderate, with regression coefficients (R^2) of 0.51 and 0.50, respectively, suggesting their potential as biological control agents. Furthermore, both species exhibited Type II functional responses with strong dependency values (r: 0.73 for *C. melanophthalmus* and r: 0.7,1 for *Scymnus* spp.), reinforcing their potential effectiveness in controlling *A. tegalensis*.

This study revealed a temporal mismatch between predator emergence and the population peak of *A. tegalensis*. While scale insect densities increased rapidly between 6.5 and 10.5 months, most predator species appeared only after the pest had reached high levels. This delay significantly limits the effectiveness of natural pest suppression in the field. Among the observed predators, *C. melanophthalmus* and *Scymnus* spp. showed the strongest potential for biological control, supported by moderate correlations with pest abundance and consistent field presence. However, their population densities remained low, reducing their capacity to suppress pest outbreaks effectively. These findings align with those of Costamagna et al. (2015), who noted that natural enemies often exert limited control unless their population dynamics closely track those of the pest.

Laboratory trials confirmed the predation potential of *C. melanophthalmus*, which exhibited a higher average predation rate than *Scymnus* spp., reaching a plateau of approximately 9-10 prey per day, whereas *Scymnus* spp. peaked 8-9 prey per day (Figure 2). Both of them showed Type II functional response characterized by increased predation at low to moderate prey densities, followed by a plateau due to handling limitations. This distinction suggests that *C. melanophthalmus* may have a marginally greater predation capacity under laboratory conditions. Conversely, *Telsimia* spp. and *C. nigritus* showed weaker correlations and less stable field populations, suggesting greater environmental sensitivity or lower prey specificity. The inconsistent presence of *Telsimia* spp. further reduces its suitability for field-level pest management.

The difference in predation rate between *C. melanophthalmus* and *Scymnus* spp. is likely influenced by body size and attack behavior. The large body size of *C. melanophthalmus* provides greater physical capacity to subdue and consume *A. tegalensis,* resulting in shorter handling time and slightly higher predation plateaus (9-10 vs.8-9 prey/day). In contrast, the smaller *Scymnus* spp. exhibit lower mobility and attack speed, leading to slightly reduced predation efficiency at higher prey densities. These findings are consistent with Papanikolaou et al. (2021), who reported that predator body size directly affects handling time and attack rate, with larger predators able to consume more prey within the same period. The type II functional response observed in *C. melanophthalmus* and *Scymnus* spp. aligns with the finding of Pervez and Omkar (2005), who reported a similar pattern in coccinellid predators (*Cheilomenes sexmaculata* and *Coccinella transversalis*) exhibiting predation on aphids with handling time varying significant among species. These parallels suggest that differences in handling time, large due to predator body size, are consistent drivers of predation efficiency across coccinellid-scale insect systems. Ecologically, the ability of *Scymnus* spp. and *C. melanophthalmus* to persist, albeit at low densities, throughout the crop cycle is promising for conservation biological control. Their effectiveness could be enhanced through habitat management strategies, such as intercropping, refuge provision, or flowering strips, which support predator survival and reproduction. To strengthen integrated pest management in sugarcane, a combined approach involving conservation and augmentation is recommended. Mass rearing and periodic field releases of promising species, particularly *C. melanophthalmus and Scymnus* spp, may help synchronize predator presence with early *A. tegalensis* development. Integrating biological control with cultural practices such as field sanitation and plant health maintenance can further improve pest management outcomes.

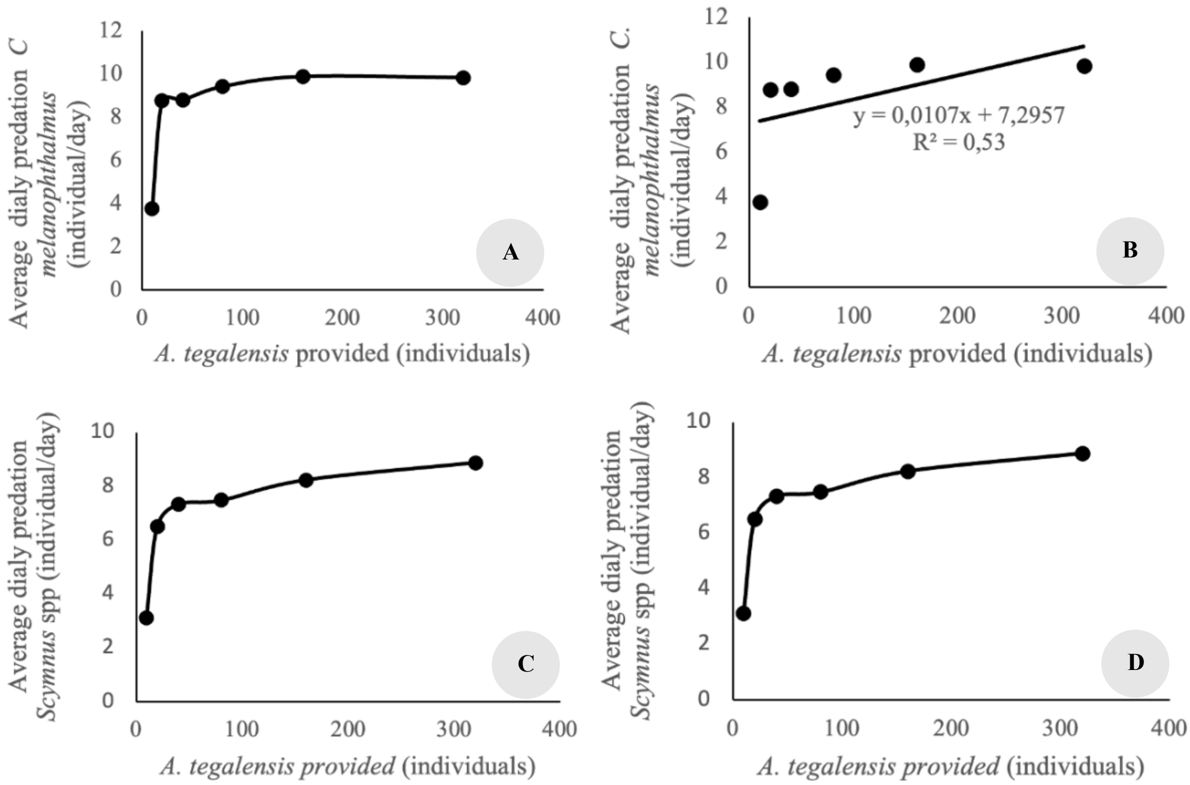

Figure 1. Type II functional response curve and regression model showing the predation of *Chilocorus melanophtalmus* (A and B) and *Scymnus* spp. (C and D) on *Aulacaspis tegalensis*

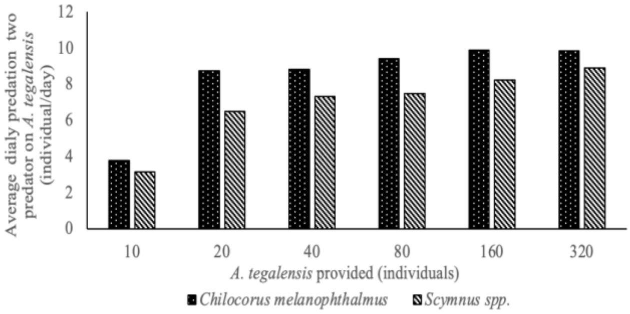

Figure 2. Comparison of average daily predation by two coccinellid predators on *Aulacaspis tegalensis* at varying prey densities

In conclusion, two species of natural enemies, namely the coccinellid predator *C. melanophthalmus* and *Scymnus* spp., are considered sufficient to suppress pest populations of sugarcane scale insect. In terms of ecosystem processes, the loss of one species may not significantly affect overall functioning because the other species can compensate for the lost species. It is expected that the presence of two natural enemies of the pest is sufficient for ecosystem stability, so that there is no explosion of the sugarcane scale insect *A. tegalensis.*

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