Journal of Biological Control, 40(3): 00-00, 2026, DOI: 10.18311/jbc/2026/55575



Research Article

Evaluation of ovicidal effects and post-hatching nymphal mortality of selected agrochemicals on the eggs of black assassin bug (*Sycanus collaris* (Fabricius)) (Hemiptera: Reduviidae), a predator of the tea mosquito bug

Annet Babu[1*], Prabhu Arjunan[1], Chandrasekaran Praveenkumar[2], T. P. Rabeesh[1] and Saravanan Balasundaram[3]

[1]*Entomology Division, UPASI TRF Tea Research Institute, Valparai – 642127, Coimbatore, Tamil Nadu, India*

[2]*ICAR – National Bureau of Agricultural Insect Resources, Bengaluru – 560024, Karnataka, India*

[3]*National Institute of Mental Health and Neurosciences, Bengaluru – 560029, Karnataka, India*

**Corresponding author E-mail*: annetbabuk@gmail.com

ABSTRACT: *Sycanus collaris* (Fabricius) (Hemiptera: Reduviidae), commonly known as the black assassin bug, is an important predatory insect associated with tea ecosystems and contributes to the natural suppression of insect pests such as the tea mosquito bug. However, insecticide exposure may adversely affect non-target predatory insects. The present study evaluated the ovicidal activity and post-hatching nymphal mortality of five insecticides, *viz*., Quinalphos 25 EC, Deltamethrin 2.8 EC, Dimethoate 30 EC, Thiacloprid 240 SC and Thiamethoxam 25 WG, against 1- to 3-day-old eggs of *S. collaris* under laboratory conditions. Egg batches were treated at lower, recommended and higher concentrations, and ovicidal activity and mortality of emerging nymphs were recorded. Deltamethrin 2.8 EC and Thiamethoxam 25 WG showed comparatively higher ovicidal activity, whereas Quinalphos 25 EC and Dimethoate 30 EC caused complete post-hatching nymphal mortality. Thiacloprid 240 SC showed comparatively lower effects on both eggs and emerging nymphs under the tested conditions. The results demonstrate that insecticide effects on *S. collaris* cannot be assessed from egg mortality alone, as substantial mortality may also occur among nymphs emerging from treated eggs. These findings highlight the need to consider both egg and post-hatching effects when selecting insecticides for integrated pest management in tea ecosystems.

KEYWORDS: Black assassin bug, insecticide selectivity, ovicidal activity, post-hatching mortality, *Sycanus collaris*, tea ecosystem

(Article chronicle: Received: 21-04-2026; Revised:20-08-2026; Accepted: 01-09-2026)

INTRODUCTION

Tea, *Camellia sinensis* (O.) Kuntze, is one of the most widely consumed beverages worldwide after water and is valued for its numerous health-promoting properties (McKay & Blumberg, 2002). Tea is rich in bioactive compounds, particularly antioxidants, which are associated with several beneficial properties, including anti-carcinogenic, antimicrobial and anti-inflammatory activities (Soni *et al.,* 2015). Tea is cultivated commercially in approximately 50 countries across the world (Lei *et al.,* 2022). Among the major tea-producing countries, India occupies a prominent position, and the tea industry makes a significant contribution to the country's economy (Kumar *et al.,* 2021).

Tea production is severely affected by the infestation of numerous insect and mite pests, which can adversely affect both the yield and quality of tea (Maleque *et al.,* 2025). Among the major insect pests of tea, the tea mosquito bug, *Helopeltis theivora* Waterhouse, is one of the most destructive pests. Both nymphs and adults feed on tender shoots by inserting their piercing-sucking mouthparts, resulting in characteristic lesions, shoot damage and deterioration in tea yield and quality (Roy *et al.,* 2015).

Under severe infestation, crop losses may reach up to 100% (Yao *et al.,* 2025).

Chemical control is one of the common ways to manage insect pests in tea. It works quickly and reduces pest population effectively. Frequent use of synthetic insecticides without care can cause problems like pesticide residue buildup in tea and resistance development in target organisms. The use of synthetic insecticides also affects natural enemies that help keep pest populations in check (Geiger *et al*., 2010; Desneux *et al*., 2007). Because of these issues, there is growing interest in pest management methods. These methods aim to reduce reliance on insecticides while still keeping pests under control.

Biological control plays an important role in sustainable pest management. It offers value for money compared to chemical control. For example, biological control gives a return of 1:250 while chemical control only returns 1:2 to 1:5 (Bale *et al*., 2007). This makes it more cost-effective and less dependent on pesticides. The conservation of natural enemies, particularly predatory insects are therefore an important component of sustainable pest management (Basnet & Mukhopadhyay, 2014). Among predatory insects, reduviid bugs (Hemiptera: Reduviidae) are considered effective biological control agents because of their polyphagous feeding habit, active predatory behaviour and relatively large body size (Kakoti *et al.*, 2025). Their piercing-sucking mouthparts enable them to prey upon a wide range of insect species (Wang *et al.*, 2020).

The black assassin bug, *S. collaris*, is an abundant reduviid predator in the tea ecosystem and has been reported as an important natural enemy of *H. theivora* (Srikumar *et al.,* 2017). The species can also be successfully mass-multiplied under laboratory conditions, making it a promising organism for augmentative biological control. For the management of *H. theivora,* the release of 1000 reduviid nymphs ha^{-1} is recommended under the Plant Protection Code (Tea Board of India, 2026).

Although reduviid bugs are considered relatively tolerant to several pesticides and biopesticides, their survival and predatory performance may still be affected by pesticide exposure (Sahayaraj, 2014). The extensive use of synthetic insecticides can disrupt predator–prey interactions and reduce the effectiveness of natural enemies in pest control (Geiger *et al.,* 2010). In tea ecosystems, pesticide exposure may adversely affect beneficial predatory insects, including reduviid bugs, thereby reducing their contribution to the biological regulation of pests such as *H. theivora* (Rabeesh *et al.,* 2024). The reduction of natural-enemy populations may subsequently contribute to pest resurgence and secondary pest outbreaks (Desneux *et al.,* 2007).

Therefore, finding out the compatibility of pesticides with natural enemies is an essential component of Integrated Pest Management (IPM) programmes (Sriraksha *et al.,* 2021). In particular, evaluating the effects of insecticides on different developmental stages of natural enemies is important for selecting pesticides that are effective against target pests while causing minimal adverse effects on beneficial organisms. The assessment of pesticide toxicity to the eggs of predatory insects is particularly relevant because egg exposure may affect both egg viability and the survival of newly emerged nymphs (David & Horsburgh, 1985). Understanding these effects can help in developing pesticide application schedules that are compatible with the conservation and augmentation of natural enemies.

Ovicidal activity refers to the ability of a chemical treatment to cause mortality in eggs, thereby interfering with successful development and reducing the subsequent population of the organism (Basavanneppa *et al.,* 2014). In addition to direct egg mortality, pesticide exposure may produce delayed effects on nymphs emerging from treated eggs. Such post-hatching nymphal mortality represents the mortality of newly emerged nymphs following their emergence from pesticide-treated eggs (Romero *et al.,* 2014). Both ovicidal and post-hatching effects are therefore important parameters for assessing the overall toxicity of pesticides to predatory insects.

In the current study, the ovicidal effects and post-hatching nymphal mortality caused by five insecticides commonly used for the management of *H. theivora*, namely Quinalphos 25 EC, Deltamethrin 2.8 EC, Dimethoate 30 EC, Thiacloprid 240 SC and Thiamethoxam 25 WG, were evaluated against the eggs of *S. collaris*. The study aimed to assess the effects of these insecticides at different dosage levels and to determine their potential compatibility with *S. collaris* for integration of chemical and biological control strategies in tea pest management.

MATERIALS AND METHODS

Laboratory rearing of Black assassin bug (*Sycanus collaris*) and egg batch collection

Sycanus collaris insects were reared in plastic containers (26 × 11 cm) by feeding rice moth, *Corcyra cephalonica* (Stainton) larvae at 23 ± 2°C and 87 ± 3% humidity at the



Figure 1. (a). The whole egg batch of *S. collaris*, **(b).** Newly hatched nymphs from the control egg batch of *S. collaris,* **(c).** Treated egg with dead emerged nymphs.

United Planters Association of Southern India (UPASI), Tea Research Institute, Valparai, India. From the stock culture, one- to three-day-old egg batches of *S. collaris* were used for the experiment. A total of eighty egg batches were used for this study (Figure 1). The number of eggs present in each egg batch was counted and noted before spraying, and it was 77 ± 12 eggs. Three dosages of each of the five chemicals (Table 1) were tested along with one untreated control. For each treatment, five replications were tested, and for each replication one egg batch was used.

Chemical preparation

For the evaluation of ovicidal activity, Quinalphos 25 EC (Ekalux) manufactured by Syngenta India Limited, Dimethoate 30 EC (Tafgor) manufactured by Rallis India Limited, Deltamethrin 2.8 EC (Decis 2.8 EC) manufactured by Bayer Crop Science Limited, Thiamethoxam 25 WG (Actara) manufactured by Syngenta India Limited and Thiacloprid 240 SC (Alanto) manufactured by Bayer Crop Science Limited were purchased. The recommended dosages of the chemicals were considered according to the PPC recommendation (Central Insecticides Board & Registration Committee, 2026). Half of the recommended

Table 1. Plant protection code recommended insecticides for the management of *Helopeltis theivora* (Central Insecticides Board & Registration Committee CIB & RC, 2026)

Insecticides	Dosage
Quinalphos 25 EC	1000 ml/ha
Dimethoate 30 % EC	750 ml/ha
Deltamethrin 2.8 EC	500 ml/ha
Thiamethoxam 25 WG	100 g to 125 g/ha
Thiacloprid240 SC	750 ml/ha
Acetamiprid 20% SP	120g/ha
Imidacloprid 17.8% SL	120 ml/ha
Bifenthrin 8 SC	750 ml/ha
Clothianidin 50 WDG	80 g/ha

Table 2. Lower, recommended and higher dosages of the chemicals used for the test

Chemical	Lower dosage	Recommended dosage	Higher dosage
Quinalphos 25 EC	1 ml/L	2 ml/L	4 ml/L
Dimethoate 30 EC	1 ml/L	2 ml/L	4 ml/L
Deltamethrin 2.8 EC	0.5 ml/L	1 ml/L	2 ml/L
Thiamethoxam 25 WG	0.1 mg/L	0.2 mg/L	0.4 mg/L
Thiacloprid 240 SC	0.5 ml/L	1 ml/L	2 ml/L

dosage and double the recommended dosage were used as lower and higher dosages, respectively (Table 2).

Ovicidal test

The ovicidal effect of the chemicals was tested using the method of Preetha *et al.,* 2007. The number of eggs present in each egg batch was counted and noted before spraying. After that, all five chemicals were sprayed on the egg batches in three different dosages (each replicate five times) using a hand sprayer (1L capacity) under laboratory conditions. The water-sprayed egg batches served as a control. The sprayed egg batches were kept for incubation in separate plastic containers (11 x 7.5 cm) covered with muslin cloth. After the incubation period, the ovicidal percentage was calculated as follows,

$$\text{Ovicidal activity \%} = \frac{\text{Total number of eggs in the batch} - \text{Number of eggs hatched in the batch}}{\text{Total number of eggs in the batch}} \times 100$$

(Valizadeh *et al.,* 2021)

Post-hatching nymphal mortality %

Additionally, the delayed effect of the chemicals was observed in the immediately hatched nymphs' mortality and documented as the post-hatching nymphal mortality percentage calculated by

$$\text{Post} - \text{hatching nymphal mortality} = \frac{\text{Number of nymphs dead immediately after hatching}}{\text{Total number of nymphs hatched from the egg batch}} \times 100$$

(Gonella *et al*., 2019)

Statistical analysis

Data obtained from the ovicidal bioassay were expressed as percentages and subjected to arcsine square-root transformation. The transformed data were checked for normality and analysed using two-way factorial analysis of variance (ANOVA) to determine the effects of insecticide formulation, dose level and their interaction. Treatment means were compared using the least significant difference (LSD) test at the 5% significance level, and differences were considered significant at $P < 0.05$. All statistical analyses were performed using GRAPES (General R-Shiny Based Analysis Platform Empowered by Statistics), version 1.0.0 (Gopinath *et al*., 2020). Data visualisation was conducted using R version 4.5.2 with the ggplot2 package.

RESULTS AND DISCUSSION

The ovicidal effect and post-hatching nymphal mortality of selected agrochemicals were evaluated against the eggs of *Sycanus collaris* at three dosages, namely lower dosage (LD), recommended dosage (RD) and higher dosage (HD). The results revealed notable variation in the response of egg mortality and subsequent post-hatching nymphal mortality among the tested insecticides.

Ovicidal activity varied among the insecticide formulations and dose levels, with significant differences observed in the statistical analysis (Table 3). Deltamethrin 2.8 EC recorded the highest ovicidal activity across all three dose levels, with transformed mean values increasing from 0.468 ± 0.031 at the lower dose (0.5 ml/L) to 0.539 ± 0.031 at the recommended dose (1 ml/L) and 0.592 ± 0.027 at the higher dose (2 ml/L). The higher dose of Deltamethrin 2.8 EC recorded the highest transformed response and was assigned to the highest statistical group (a). The comparatively higher response of deltamethrin observed in the present study is also supported by observations on the eggs of the tea mosquito bug, *Helopeltis theivora*. Roy *et al.* 2010) compared the susceptibility of *H. theivora* eggs to several insecticides and reported deltamethrin among the more toxic compounds, whereas dimethoate and quinalphos showed comparatively lower toxicity. Although the test insect and experimental concentrations differed from those of the present study, the findings provide a useful comparison within the tea agroecosystem.

Thiamethoxam 25 WG showed a pronounced increase in response at the higher dose, with transformed values of 0.297 ± 0.016, 0.334 ± 0.021 and 0.521 ± 0.032 at the lower (0.1 mg/L), recommended (0.2 mg/L) and higher doses (0.4 mg/L), respectively. The lower and recommended doses were statistically similar (group d), whereas the higher dose was assigned to group (b), indicating a marked increase in ovicidal activity at the higher dose. Dimethoate 30 EC exhibited a gradual increase in transformed response from 0.209 ± 0.062 at the lower dose (1 ml/L) to 0.247 ± 0.021 at the recommended dose (2 ml/L) and 0.315 ± 0.009 at the higher dose (4 ml/L). Quinalphos 25 EC showed comparatively low ovicidal activity, with transformed values of 0.182 ± 0.065, 0.207 ± 0.052 and 0.229 ± 0.019 at the lower (1 ml/L), recommended (2 ml/L) and higher doses (4 ml/L), respectively. Thiacloprid 240 SC recorded the lowest responses overall, with transformed values of 0.166 ± 0.033, 0.176 ± 0.043 and 0.210 ± 0.028 across the respective doses. The lower ovicidal responses observed

Table 3. Ovicidal response of different insecticide formulations at three different dose levels

Insecticide formulation	Lower dose	Recommended dose	Higher dose
Quinalphos 25 EC (Ekalux)	0.182 ± 0.065^{e}	0.207 ± 0.052^{ef}	0.229 ± 0.019^{f}
Dimethoate 30 EC (Tafgor)	0.209 ± 0.062^{ef}	0.247 ± 0.021^{e}	0.315 ± 0.009^{d}
Deltamethrin 2.8 EC (Decis 2.8 EC)	0.468 ± 0.031^{c}	0.539 ± 0.031^{b}	0.592±0.027^{a}
Thiamethoxam 25 WG (Actara)	0.297 ± 0.016^{d}	0.334 ± 0.021^{d}	0.521 ± 0.032^{b}
Thiacloprid 240 SC (Alanto)	0.166 ± 0.033^{f}	0.176 ± 0.043^{f}	0.210 ± 0.028^{ef}

Values are presented as mean ± SD of the untransformed percentage data. Statistical analysis was performed on arcsine square-root-transformed data. Means followed by the same superscript letter are not significantly different according to the LSD test at $P < 0.05$.

Table 4. Effect of insecticides on post-hatching nymphal mortality

Insecticide formulation	Lower dose	Recommended dose	Higher dose
Quinalphos 25 EC (Ekalux)	1.571 ± 0.00^{a}	1.571 ± 0.00^{a}	1.571 ± 0.00^{a}
Dimethoate 30 EC (Tafgor)	1.571 ± 0.00^{a}	1.571 ± 0.00^{a}	1.571 ± 0.00^{a}
Deltamethrin 2.8 EC (Decis 2.8 EC)	0.369 ± 0.019^{d}	0.427 ± 0.024^{c}	0.834 ± 0.025^{b}
Thiamethoxam 25 WG (Actara)	0.000 ± 0.00^{f}	0.000 ± 0.00^{f}	0.279 ± 0.010^{e}
Thiacloprid 240 SC (Alanto)	0.000 ± 0.00^{f}	0.000 ± 0.00^{f}	0.000 ± 0.00^{f}

Values are mean ± SD (n = 5). Means followed by the same superscript letter are not significantly different at $P \leq 0.05$ according to the critical-difference comparison for the insecticide × dose interaction. The lower, recommended and higher doses correspond to ½×, 1× and 2× the recommended dose, respectively. The factorial analysis showed significant effects of insecticide, dose and their interaction ($P < 0.001$).

with dimethoate and quinalphos in the present study are also comparable with the lower relative susceptibility of *H. theivora* eggs to these compounds reported by Roy *et al*. 2010). In that study, the susceptibility ranking placed dimethoate and quinalphos below deltamethrin, although the relative toxicity values were obtained from a different experimental system and therefore should not be directly compared with the present percentage responses.

Post-hatching nymphal mortality varied significantly among insecticide formulations, dose levels and their interaction ($P < 0.001$) (Table 4). Quinalphos 25 EC and Dimethoate 30 EC resulted in complete post-hatching nymphal mortality (100.00%) at all three dose levels. Deltamethrin 2.8 EC exhibited a dose-dependent increase in nymphal mortality, from 13.00 ± 1.25% at the lower dose (0.5 ml/L) to 17.20 ± 1.78% at the recommended dose (1 ml/L) and 54.80 ± 2.49% at the higher dose (2 ml/L). Thiamethoxam 25 WG caused no post-hatching nymphal mortality at the lower (0.1 mg/L) and recommended doses (0.2 mg/L), while mortality increased to 7.60 ± 0.54% at the higher dose (0.4 mg/L). Thiacloprid 240 SC did not cause any post-hatching nymphal mortality at any of the tested dose levels.

The marked difference between ovicidal response and post-hatching mortality is an important observation of the present study (Figure 2). In particular, quinalphos and dimethoate showed comparatively lower ovicidal responses, but all nymphs that emerged from the treated eggs subsequently died. Thus, in the present experimental conditions, egg mortality alone did not describe the complete outcome following insecticide exposure. A similar approach has been used by Kammatterikunnu and Thattanteparambil (2024), who evaluated both hatchability of *S. collaris* egg batches and survival of nymphs emerging from treated eggs. Their study showed that insecticide treatment of eggs could affect the subsequent survival of emerging nymphs.

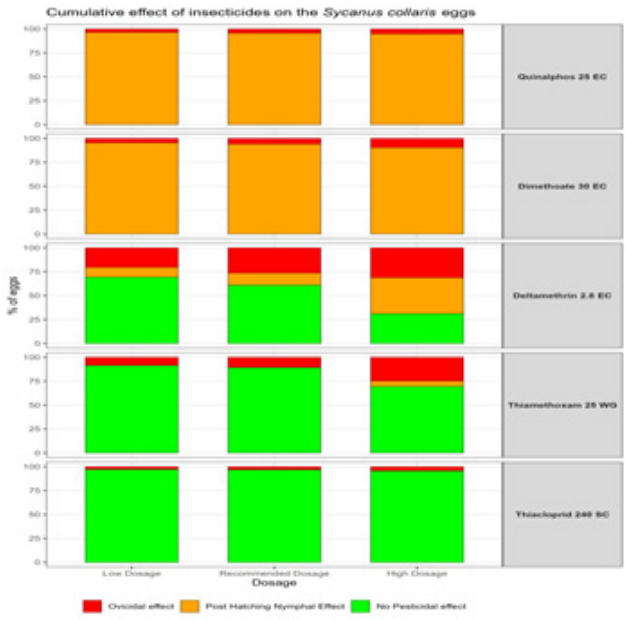


Figure 2. Cumulative response of the eggs of *Sycanus collaris* to different insecticides at three dose levels. Values are expressed as the percentage of eggs showing ovicidal effect, post-hatching nymphal mortality, and no observed pesticidal effect.

The result obtained with quinalphos in the present study is consistent with earlier observations on *S. collaris*. Sriraksha *et al*., (2021) recorded very high mortality following exposure of *S. collaris* nymphs to quinalphos, with 100% mortality in the first and second instars and progressively lower, although still high, mortality in later stages and adults. Thus, the complete mortality of nymphs emerging from quinalphos-treated eggs in the present study is in agreement with the high susceptibility of *S. collaris* to quinalphos reported previously, while the exposure route and developmental stage differed between the studies.

The high toxicity of quinalphos to *S. collaris* has also been reported by Kammatterikunnu and Thattanteparambil (2025). In their laboratory study, quinalphos produced higher mortality than thiamethoxam and thiacloprid across the developmental stages tested. Their results further showed differences in susceptibility among the developmental stages, with younger nymphal instars generally showing greater mortality than adults. These observations provide supporting evidence for the high post-hatching mortality associated with quinalphos in the present study, while the present experiment specifically demonstrates this response following exposure at the egg stage.

The complete post-hatching mortality caused by Dimethoate 30 EC, despite its comparatively lower ovicidal activity, also indicates that the response of *S. collaris* may differ between the egg and newly emerged nymphal stages. Earlier work on *S. collaris* has similarly shown that insecticide susceptibility differs among developmental stages. Kammatterikunnu and Thattanteparambil (2025) observed greater susceptibility of several earlier nymphal stages than adults following exposure to the tested insecticides. Therefore, the present findings further emphasise the importance of considering the developmental stage when assessing the effects of insecticides on this predator.

Deltamethrin 2.8 EC showed both relatively high ovicidal activity and an increase in post-hatching mortality with increasing dose. The dose-related increase in nymphal mortality observed in the present study is consistent with previous observations of toxicity of pyrethroid insecticides towards reduviid predators. The study by Kammatterikunnu and Thattanteparambil (2025) reported toxicity of deltamethrin to *S. collaris*, while earlier work cited in that study reported toxic effects of deltamethrin and cypermethrin against *Sycanus dichotomus*. These studies provide supporting evidence that pyrethroid exposure can affect reduviid predators, although differences in insect species, life stage, formulation and exposure conditions need to be considered when making comparisons.

Thiamethoxam 25 WG showed a different pattern, with a pronounced increase in ovicidal response at the higher dose but only 7.60 ± 0.54% post-hatching nymphal mortality. A comparatively lower toxicity of thiamethoxam to *S. collaris* has also been reported by Sriraksha *et al.* (2021), who recorded lower mortality with thiamethoxam than with quinalphos in nymphal and adult stages. In their study, mortality caused by thiamethoxam decreased from 29.17% in the first instar to 9.17% in adults, whereas quinalphos caused 100% mortality in the first and second instars and 83.33% in adults. The present study therefore shows a similar contrast in relative toxicity between these two insecticides, although the present exposure occurred at the egg stage.

Kammatterikunnu and Thattanteparambil (2025) also reported comparatively lower toxicity of thiamethoxam and thiacloprid than quinalphos, dimethoate and deltamethrin in their laboratory assessment of *S. collaris*. This provides additional support for the relatively low post-hatching

mortality observed with thiamethoxam and the absence of mortality observed with thiacloprid in the present study. However, the present results also show that thiamethoxam was not without effect at the egg stage, as its ovicidal response increased substantially at the higher dose. Therefore, its effect should be considered separately for egg viability and post-hatching survival rather than described simply as "safe".

Thiacloprid 240 SC recorded comparatively low ovicidal activity and did not cause post-hatching nymphal mortality at any of the tested dose levels. This observation is broadly consistent with the comparatively lower toxicity of thiacloprid reported for *S. collaris* by Kammatterikunnu and Thattanteparambil (2025). Their study evaluated direct exposure of different nymphal instars and adults and found thiacloprid to be among the comparatively less toxic insecticides tested. Since the present study involved egg exposure followed by observation of emerging nymphs, the agreement between the two studies should be interpreted as supportive rather than as evidence of identical toxicity across developmental stages.

The present findings also agree with the broader observation that pesticide effects on natural enemies can differ according to insecticide and developmental stage. Kammatterikunnu and Thattanteparambil (2025) specifically highlighted differences in susceptibility among *S. collaris* developmental stages, while Sriraksha *et al.,* (2021) reported greater susceptibility of nymphal stages than adults for several insecticides. Such variation indicates that insecticide compatibility with *S. collaris* should be evaluated with consideration of the particular developmental stage exposed.

The findings are particularly relevant to the tea ecosystem because *S. collaris* is a predatory reduviid associated with tea and has been reported as a predator of tea mosquito bug. Kammatterikunnu and Thattanteparambil (2024) also emphasised the role of *S. collaris* as a natural enemy in the tea agroecosystem and evaluated pesticide effects on its egg batches. Thus, information on egg-stage susceptibility can complement earlier studies that focused mainly on nymphal and adult stages.

CONCLUSION AND FUTURE PERSPECTIVES

Overall, the present study demonstrates considerable variation among the tested insecticides in their effects on *S. collaris* eggs and the nymphs emerging from treated eggs. Quinalphos and dimethoate caused complete post-hatching nymphal mortality despite comparatively lower ovicidal responses, whereas deltamethrin showed relatively high ovicidal activity together with increasing nymphal mortality at higher doses. Thiamethoxam showed increased ovicidal activity at the higher dose but limited post-hatching mortality, while thiacloprid showed comparatively low ovicidal activity and no post-hatching nymphal mortality under the conditions tested. These observations indicate that evaluation of both egg mortality and subsequent nymphal survival can provide more complete information on the response of *S. collaris* to insecticide exposure.

From an IPM perspective, the results suggest that insecticides producing high mortality of *S. collaris* during the egg-to-nymph transition, particularly quinalphos and dimethoate under the present laboratory conditions, should be considered carefully where conservation of this predator is intended. However, the present laboratory observations should not be directly extrapolated to field-level compatibility because exposure conditions, spray deposition, environmental factors and subsequent predator–prey interactions may differ under field conditions. Further semi-field and field evaluations would therefore be useful to determine the compatibility of these insecticides with *S. collaris* in tea pest-management programmes.

ACKNOWLEDGEMENTS

The authors are thankful to all the staff of the Division of Entomology in UPASI Tea Research Institute, Valparai, for the motivation and support. The authors gratefully acknowledge Gassin Pierre Pvt. Ltd. for the financial support provided towards the publication of this research work through the NUTRASTICK project.

REFERENCES

Bale, J. S., Van Lenteren, J. C., & Bigler, F. 2007. Biological control and sustainable food production. *Philos Trans R Soc B: Biol Sci*, **363**(1492): 761.

Basavanneppa, B. B., Balikai, R., & Kambrekar, D. 2014. Ovicidal action of newer insecticide molecules against the eggs of *Helicoverpa armigera* (Hubner). *Int J Agric Stat Sci*, **10**: 189–191.

Basnet, K., & Mukhopadhyay, A. 2014. Biocontrol potential of the lynx spider *Oxyopes javanus* (Araneae: Oxyopidae) against the tea mosquito bug, *Helopeltis theivora* (Heteroptera: Miridae). *Int J Trop Insect Sci*, **34**(4): 232-238. https://doi.org/10.1017/S1742758414000538

Central Insecticides Board & Registration Committee (CIB&RC). 2026. *Central Insecticides Board and Registration Committee.* Directorate of Plant Protection, Quarantine and Storage, Department of Agriculture and Farmers Welfare, Government of India. Available at: https://ppqs.gov.in/divisions/central-insecticide-board-registration-committee

David, P. J., & Horsburgh, R. L. 1985. Ovicidal activity of methomyl on eggs of pest and beneficial insects and mites associated with apples in Virginia. *J Econ Entomol*, **78**(2): 432–436. https://doi.org/10.1093/jee/78.2.432

Desneux, N., Decourtye, A., & Delpuech, J. M. 2007. The sublethal effects of pesticides on beneficial arthropods. *Annu Rev Entomol*, **52**(1): 81-106. https://doi.org/10.1146/annurev.ento.52.110405.091440 PMid: 16842032.

Geiger, F., Bengtsson, J., Berendse, F., Weisser, W. W., Emmerson, M., Morales, M. B., Ceryngier, P., Liira, J., Tscharntke, T., Winqvist, C., Eggers, S., Bommarco, R., Pärt, T., Bretagnolle, V., Plantegenest, M., Clement, L. W., Dennis, C., Palmer, C., Oñate, J. J., … Inchausti, P. 2010. Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic Appl Ecol*, **11**(2): 97–105. https://doi.org/10.1016/j.baae.2009.12.001 PMCid: PMC11856747.

Gonella, E., Orrù, B., & Alma, A. 2019. Egg masses treatment with micronutrient fertilizers has a suppressive effect on newly-emerged nymphs of the brown marmorated stink bug *Halyomorpha halys*. *Entomol Gen,* **3:** 231-238. https://doi.org/10.1127/entomologia/2019/0819

Gopinath, P. P., Parsad, R., Joseph, B., Adarsh, V. S. 2020. *GRAPES:* General R-shiny Based Analysis Platform Empowered by Statistics. https://doi.org/10.5281/zenodo.4923220

Yao, Q., Lin, Y.-Z,. Qin, S., Lin, Z.-F. & Ji, X.-C. 2025 Characterization of feeding damage by tea mosquito bug, Helopeltis theivora Waterhouse (Hemiptera: Miridae) on Hainan Dayezhong tea cultivar. *Front Plant Sci.* **15**:1529535. https://doi.org/10.3389/fpls.2024.1529535

Kakoti, B., Das, T., Roy, S., & Babu, A. 2025. Bio-ecology and predatory potential of the family reduvidae with emphasis on utilization of their salivary toxin against pests of tea. *Munis Entomol Zool,* **20**(1): 1579-1590.

Kammatterikunnu, A., & Thattanteparambil, R. 2024. Effect of certain insecticides on egg batch of *Sycanus collaris* (Insecta: Hemiptera: Reduviidae). *Inter J Fauna Biol Stud*, **11**(6): 08-11. https://doi.org/10.22271/23940522.2024.v11.i6a.1053

Kammatterikunnu, A., & Thattanteparambil, R. 2025. Stage-specific sensitivity of reduviid bug, *Sycanus collaris* (Fabricius) to insecticides: a toxicity analysis in laboratory condition. *Hexapoda*, **32**(1): 26-32. https://doi.org/10.55446/hexa.2025.571

Kumar, K. R., Dashora, K., Krishnan, N., Sanyal, S., Chandra, H., Dharmaraja, S., & Kumari, V. 2021. Feasibility assessment of renewable energy resources for tea plantation and industry in India-a review. *Renew Sustain Energy Rev*, **145**: 111083. https://doi.org/10.1016/j.rser.2021.111083

Lei, X., Wang, T., Yang, B., Duan, Y., Zhou, L., Zou, Z., ... & Fang, W. 2022. Progress and perspective on intercropping patterns in tea plantations. *Beverage Plant Res*, **2**(1): 1-10. https://doi.org/10.48130/BPR-2022-0018

Maleque, M. A., Islam, A. S., Ahmod, M. M., Islam, M. S., Hasan, R., Jewel, K. N. E. A., ... & Ishii, H. R. 2025. Documentation of major pests and spectrum of pesticide usage for tea agroecosystems in Bangladesh. *Agrofor Syst*, **99**(7): 188. https://doi.org/10.1007/s10457-025-01295-5

McKay, D. L., & Blumberg, J. B. 2002. The role of tea in human health: an update. *J Am Coll Nutr*, **21**(1): 1-13. https://doi.org/10.1080/07315724.2002.10719187 PMid: 11838881.

Preetha, G., Manoharan, T., Kuttalam, S., & Stanley, J. 2007. Ovicidal action of insecticides against the Noctuiid pests of cotton. *J Plant Prot Environ*, **4**(2): 55-59.

Rabeesh, T. P., Ashif, K. K., Prabhu, A., Babu, A., & Bharathi, N. S. 2024. Studies on the effects of pesticides on natural enemies of the tea pests. *Int J Entomol Res*, **9**(7): 134–138.

Romero, A., Potter, M. F., & Haynes, K. F. 2014. Potential of essential oil-based pesticides and detergents for bed

bug control. *J Econ Entomol,* ***107***(6): 2163–2170. https://doi.org/10.1603/EC14238 PMid: 26470082.

Roy, S., Mukhopadhyay, A., & Gurusubramanian, G. 2010. Relative susceptibility of tea mosquito bug, *Helopeltis theivora* waterhouse and red spider mite, *Oligonychus coffeae* Nietner eggs to commonly used pesticides. *J Plant Prot Res.* https://doi.org/10.2478/v10045-010-0043-z

Roy, S., Muraleedharan, N., Mukhapadhyay, A., & Handique, G. 2015. The tea mosquito bug, *Helopeltis theivora* waterhouse (Heteroptera: Miridae): its status, biology, ecology and management in tea plantations. *Int J Pest Manag*, **61**(3): 179–197. https://doi.org/10.1080/09670874.2015.1030002

Sahayaraj, K. 2014. Reduviids and their merits in biological control. Basic and Applied Aspects of Biopesticides, 195–214. https://doi.org/10.1007/978-81-322-1877-7_10

Soni, R. P., Katoch, M., Kumar, A., Ladohiya, R., & Verma, P. 2015. Tea: production, composition, consumption and its potential an antioxidant and antimicrobial agent. *Int J Food Ferment Technol*, **5**(2): 95-106.

Srikumar, K. K., Sukumaran, S., Kumar, B. S., & Radhakrishnan, B. 2017. Life history and functional response of two species of Reduviids (Hemiptera: Reduviidae: Harpactorinae) in tea. *J Agric Urban Entomol*, **33**(1): 44-56. https://doi.org/10.3954/JAUE16-17.1

Sriraksha, V., Shylesha, A. N., Shivanna, B., Rangeshwaran, R., & Prameela, H. A. 2021. Effect of insecticides on predatory assassin bug, *Sycanus collaris* (Fabricius) (Hemiptera: Reduviidae). *J Biol Control*, **35**(4):272-276. https://doi.org/10.18311/jbc/2021/29159

Tea Board of India. 2026. Plant protection code for tea (Version 19). Ministry of Commerce & Industry, Government of India.

Valizadeh, B., Jalali Sendi, J., Oftadeh, M., Ebadollahi, A., & Krutmuang, P. 2021. Ovicidal and physiological effects of essential oils extracted from six medicinal plants on the elm leaf beetle, *Xanthogaleruca luteola* (Mull.). *Agronomy*, ***11***(10): 2015. https://doi.org/10.3390/agronomy11102015

Wang, Y., Zhang, J., Wang, W., Brożek, J., & Dai, W. 2020. Unique fine morphology of mouthparts in *Haematoloecha nigroruſa* (Stål) (Hemiptera: Reduviidae) adapted to millipede feeding. *Insects*, **11**(6): 386. https://doi.org/10.3390/insects11060386 PMid: 32580387 PMCid: PMC7349294.

AUTHOR CONTRIBUTUION

Annet Babu: Conceptualization, identification of the research problem, methodology, investigation, laboratory experiments, data collection, data analysis, interpretation of results, and writing. Prabhu Arjunan: Methodology, statistical analysis, review and editing of the manuscript, and major scientific guidance and support. Chandrasekaran Praveenkumar: Statistical data generation and interpretation, writing of major sections of the manuscript, and review and editing. T. P. Rabeesh: Supervision, provision of specimens required for the study and review and editing of the manuscript. Saravanan Balasundaram: Data visualization, graphical representation of the results and review and editing. All authors read and approved the final version of the manuscript.