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Application of *Gaultheria* essential oil attractant to increase abundance zigzag ladybird beetle (*Cheilomenes sexmaculata*) and other coccinellids

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Abstract. *Efendi S, Dadang, Winasa IW, Nurmansyah A. 2025. Application of* Gaultheria *essential oil attractant to increase abundance zigzag ladybird beetle (*Cheilomenes sexmaculata*) and other coccinellids. Biodiversitas 26: 2674-2683.* *Gaultheria* essential Oil (GeO) has the potential to be used as an attractant for *Cheilomenes sexmaculata* because of its high Methyl Salicylate (MeSA) content. The research aimed to evaluate the effectiveness of GeO attractant against *C. sexmaculata* and its effect on other coccinellids. The tested GeO attractant doses were 0.25 mL, 0.5 mL, 1 mL, and 2 mL/dispenser. The data was analyzed with the Kruskal-Wallis non-parametric median test, with a Mann-Whitney post-test corrected Holm test. The analysis uses the ggstatsplot package version 0.13.0 in R Studio software version 4.4.2. The causal relationship between attractants, abundance, coccinellid richness, and chili (*Capsicum annuum*) yield was analyzed using a Structural Equation Model (SEM). The results showed that GeO attractant affects the abundance of *C. sexmaculata*. The attractant GeO also accelerates the presence of *C. sexmaculata* in chili crops. In addition, GeO attractants also affect the abundance of other predatory coccinellids, namely *Micraspis lineata*, *Harmonia decussata*, *Coelophora maculata*, *Coleophora inaequalis*, *Scymnus* sp., *Curinus coeruleus*, *Coccinella transversalis*, and *Cryptolaemus montrouzieri*. The application of GeO attractants, abundance of *C. Sexmaculata* and *Aphis gossypii* are directly and significantly related to chili yield. GeO attractant can be a new component of Integrated Pest Management (IPM) to control *A. gossypii* in chili cultivation.

Keywords: *Aphis gossypii*, coccinellids, diversity, ladybirds, semiochemicals

Abbreviations: GeO: Gaultheria essential Oil; HIPVs: Herbivore Induced Plant Volatiles (HIPVs); MeSA: Metil Salisilat

INTRODUCTION

Naturally, the presence of *Cheilomenes sexmaculata* (Fabricius, 1781) in chili crops (*Capsicum annuum*) was always late compared to *Aphis gossypii* (Glover, 1877), which is its prey. This causes *C. sexmaculata* to be unable to control the high growth rate of the *A. gossypii* population (Yi et al. 2023). The dispersal of *C. sexmaculata* was also relatively fast when it is in chili crops. High natural enemy dispersion was a major constraint to biological control in the field, with failure rates as high as 64% (Collier and Van Steenwyk 2020). Heimpel and Asplen (2021) also highlight excessive dispersion as a major cause of augmentation failure. Therefore, an effective strategy was needed to manipulate the presence and dispersal of *C. sexmaculata* in the field. One interesting approach was using semiochemicals, which involves using volatile attractant compounds to manipulate the behavior of natural enemies. Semiochemicals can manipulate the distribution of coccinellids in the field (Obrycki et al. 2019). Integrating semiochemicals to modify the behavior of natural enemies can reduce dispersal in the field (Kelly et al. 2014).

Semiochemicals have an important role in biological control because they are involved in interspecies chemical communication between plants, pests, predators and parasitoids (Thompson et al. 2022). Herbivore Induced Plant Volatiles (HIPVs) are a promising semiochemical candidate as an attractant (Kelly et al. 2014). HIPVs are important cues that predators and parasitoids use to find hosts or prey (Aartsma et al. 2017). Plants naturally produce MeSA as HIPVs to attract natural enemies and inhibit herbivore populations (Salamanca et al. 2019). Plants reported to emit MeSA when infested with herbivorous insects include potatoes (Bolter et al. 1997), sweet peppers (Riahi et al. 2022), and roses (Salamanca et al. 2015). The coccinellid species reported to be attracted to MeSA were *Harmonia axyridis* (Pallas, 1773) (Yang et al. 2023) and *Hippodamia convergens* (Guérin-Méneville, 1842) (Naranjo et al. 2021). Utilizing MeSA synthesis as a natural enemy attractant shows success in field tests (Razo-Belman and Ozuna 2023). The MeSA application on cranberry fields can attract *H. convergens* and *Chrysoperla rufilabris* (Burmeister, 1839) (Salamanca et al. 2017). Recently, Xu et al. (2024) reported a significant increase in the presence of *H. axyridis*, *Propylaea japonica* (Thunberg, 1781), and other predators such as *Syrphus corollae* (Fabricius, 1794) and *Chrysoperla sinica* (Tjeder, 1936) in corn (*Zea mays*) crops to which MeSA was applied. This evidence shows that MeSA has great potential for pest management, especially for aphids.

Manipulating MeSA using natural forms has the potential to improve biological control. MeSA is naturally contained in gaultheria essential oil (*Gaultheria fragrantissima*) (Trisilawati and Hadipoentyanti 2022). *Gaultheria* spp. is a potential source of essential oil. *Gaultheria* consists of 200 species spread across the world's temperate and tropical regions (Mukhopadhyay et al. 2016). In Indonesia, there are four species, namely *G. fragrantissima*, *G. leucocarpa*, *G. solitaria*, and *G. nummularioides* (Trisilawati and Hadipoentyanti 2022). The *Gaultheria* plant has not been cultivated in Indonesia. Still, it is growing wild in the areas of Mount Lawu, Tawangmangu, and Mount Dieng in Wonosobo, Indonesia, as well as in the mountains of Garut. The type of *Gaultheria* plant whose oil has been extracted by farmers is *G. fragrantissima*. GeO contains several secondary metabolites. According to Michel and Olszewska (2024), 130 volatile compounds have been detected in GeO, and MeSA is the dominant compound comprising 96.9-100% of the total. Other compounds reported from the leaves of the *G. fragrantissima* plant are quercetin-3 galactoside, caffeic acid, and urosolic acid (Mukhopadhyay et al. 2016). GeO has the potential to be utilized as a insect predator attractant due to its high MeSA content. However, the use of GeO as an attractant for *C. sexmaculata* has not been widely reported, including in Indonesia. Information about the GeO compound profile, proportion, application method, release rate, the right dispenser, and the influence of environmental factors is still poorly understood. GeO with a high MeSA content can be an environmentally friendly alternative for controlling aphids on chili crops. A comprehensive study is needed to develop an effective GeO attractant for *C. sexmaculata*. The research aimed to evaluate the effectiveness of GeO attractant to *C. sexmaculata* and its effect on other coccinellids.

MATERIALS AND METHODS

Study area and field preparation

The test was conducted in the experimental field of Department of Plant Protection of Institut Pertanian Bogor (IPB), Bogor District, West Java, Indonesia (6°33'38.9 "S 106°44'04.2" E) (Figure 1). Identification of insects was carried out in the laboratory of Biological Control, Department of Plant Protection, IPB University. The experimental area was 36 m × 31 m. In the area, 20 treatment plots measuring 6 m × 6 m were made with a distance of 1 m. In each plot, a bed measuring 6 m × 1 m was made. There were four beds in one treatment plot with a distance of 0.5 m between beds. The beds are covered with plastic mulch. In each bed, planting holes are made at a distance of 60 cm × 50 cm. There were 20 chili plants in one bed.

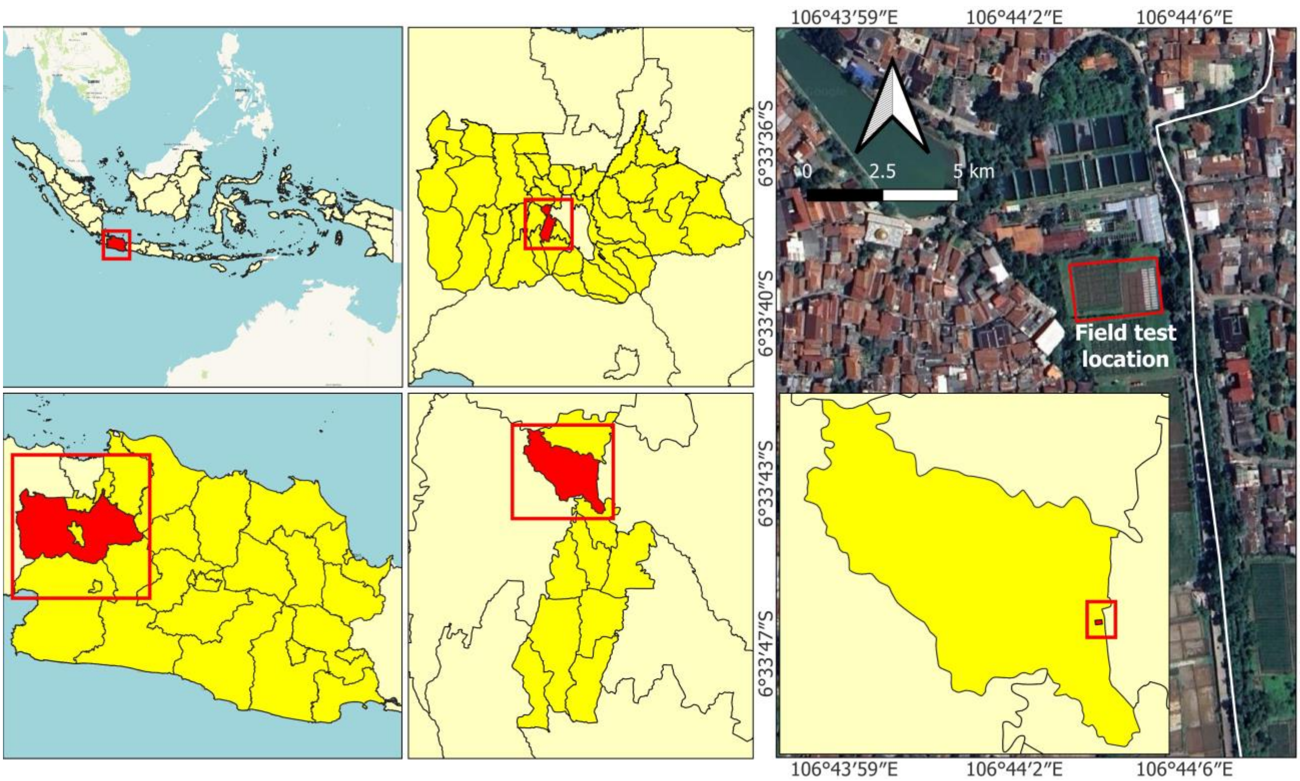


Figure 1. Field test location in the experimental field of Department of Plant Protection of Institut Pertanian Bogor, Dramaga Sub-District, Bogor District, West Java, Indonesia

Extraction and identification of *Gaultheria* essential oil

Gaultheria leaf distillation followed the method of Kumar et al. (2018), which was modified. Distillation was carried out at the Indonesia Spices, Medicinal and Aromatic Plants Instrument Standard Testing Center (ISMAPSTI), Ministry of Agriculture Indonesia. Identify compounds using a Gas Chromatography Mass Spectrometer (GC-MS), GC 789A, MS 5975C inert XL EI/CI MSD Agilent Technologies Inc., Santa Clara, USA) (Ojha et al. 2022) in the Flavor Laboratory, Indonesia Center of Rice Instrument Standard Testing (ICRIST), Ministry of Agriculture Indonesia.

Field test of *Gaultheria* essential oil attractant

Field tests used a concentration of 1% with doses of 0.25 mL/dispenser, 0.5 mL/dispenser, 1 mL/dispenser, and 2 mL/dispenser. The treatment was repeated five times. Each dose was absorbed to the dispenser. The dispensers used were made of taxwood. Dispensers were installed in the centre of each treatment plot at a height of 1 m. Attractants were applied one week after the chili plants were planted. In each treatment plot, one dispenser was installed. The treatment plots were 6 m × 6 m in size and consisted of four beds. There were 20 chili plants in one bed, with 80 plants in each treatment plot. *C. sexmaculata* observations were made directly on each treatment plot. The number of *C. sexmaculata* in each treatment plot was recorded and marked using tip-ex ink applied with a fine brush. Marking to avoid the same insects being recounted in subsequent observations. Observations were made until the chili plants were 91 days after planting. The dispensers in each treatment were changed once a week. Other predatory Coccinellidae were collected in storage bottles previously filled with 75% alcohol. The samples were identified at the genus or species level based on Ruchin et al. (2019) and Slipinski et al. (2020).

Analisis data

Abundance data of *C. sexmaculata* and other coccinellids were analyzed using the Kruskal-Wallis non-parametric mean test followed by the Mann-Whitney post-test, which was corrected by the Holm test. The analysis used the ggstatplot package version 0.13.0 in R Studio software version 4.4.2. The causal relationships between attractant doses, Coccinelidaae abundance and richness, aphid abundance, and chili yield were analyzed with a structural equation model (SEM) using the lavaan package version 0.6-19. Evaluation of model performance is determined by low Root Mean Square Error of Approximation (RMSEA) values and high Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI) (Xia and Yang 2019).

RESULTS AND DISCUSSION

***Gaultheria* essential oil compound**

Based on GC-MS analysis GeO contains nine compounds, and MeSA had the highest proportion, 94.90% (Table 1). According to Kumar et al. (2018), the MeSA content in GeO reached 98.04%, and Ojha et al. (2022) even reported a higher proportion of 99.89%. MeSA is an ester of salicylic acid, a phenolic compound formed from the shikimic acid pathway (Gondor et al. 2022). *Gaultheria* plants naturally possess a highly efficient enzyme that converts salicylic acid into MeSA (Chen et al. 2019). GeO contains two compounds that were thought to be attractants to natural enemies, namely MeSA and caryophyllene (Table 2). The attracted coccinellids were *H. variegata* and *S. picipes* (Yi et al. 2023). Other natural enemies attracted by MeSA include *Chrysopa nigricornis* (Burmeister, 1839), *Hemerobius* sp. (Linnaeus, 1758), *Deraeocoris brevis* (Uhler, 1904), and *Orius tristicolor* (White, 1879) (Maeda et al. 2015).

Table 1. Identified compounds and relative peak areas (%) in *Gaultheria* essential oil

Group	Compound	Relative peak area (%)
Alkuna	Methyl divinyl acetylene	0.13
Ester	Methyl salicylate	94.90
Fenilpropanoid	Eugenol	3.54
	Isoeugenol	0.06
	Acetyleugenol	0.22
Terpenoid	Citronellal	0.06
	(R)-(+)-Citronellal	0.02
	cis-Geraniol	0.46
	Caryophyllene	0.61

Table 2. GeO compounds that are suspected to be attractants to coccinellids and other natural enemies

Compound	Species coccinellids that respond	Other predatory and parasitoid species that respond	Reference
Methyl salicylate	*H. variegata*; *S. picipes*	*C. nigricornis*; *Hemerobius* sp; *Amblyseius potentillae* (Garman, 1958); *D. brevis*; *O. tristicolor*	Maeda et al. (2015); Yi et al. (2023)
Caryophyllene	*H. variegata*	*Aphidius funebris* (Mackauer, 1961); *Arma chinensis* (Fallou, 1881); *Chrysoperla carnea* (Stephens, 1836); *Trichogramma chilonis* (Ishii, 1941); *Trichogramma pretiosum* (Riley, 1879) *Cotesia marginiventris* (Cresson, 1865)	Xu et al. (2021); Munawar et al. (2022); Yi et al. (2023)

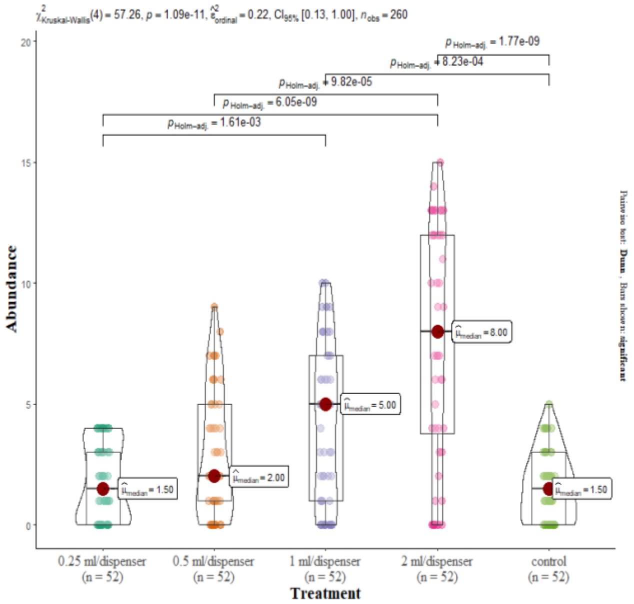


Figure 2. Violin plot showing the abundance of *C. sexmaculata* at several doses of GeO attractant. *P* holm-adj<0.001

Influence of geo attractant on the abundance of *Cheilomenes sexmaculata*

The application of GeO attractant affects the abundance of *C. sexmaculata* ($p<0.001$) (Figure 2). The highest abundance was found in the treatment with 2 mL/dispenser, significantly different from the treatments with 0.5 mL/dispenser, 0.25 mL/dispenser and without attractant, but not significantly different from the treatment with 1 mL/dispenser (Figure 2).

Influence of GeO attractant on other coccinellidae in chili crops

GeO also affects the abundance of other coccinellids. The identified species were *Micraspis lineata*, *Harmonia decussata*, *Coelophora maculata*, *Coelophora inaequalis*, *Scymnus* sp., *Curinus coeruleus*, *Coccinella transversalis*, and *Cryptolaemus montrouzieri* (Figure 3). GeO affects the abundance of *M. lineata* (p<0,001) (Figure 4.B) and *H. decussata* (Figure 4.A) in chili crops. The highest abundance of *M. lineata* and *H. decussata* were found in the 2 mL/dispenser treatment.

GeO attractants affect the abundance of *C. maculata* ($p<0.001$) (Figure 5.A). The highest abundance was found in the 2 mL/dispenser treatment, significantly different from all other treatments (Figure 5.A). The abundance of *C. maculata* was low and not even found in some treatments. The abundance of *C. maculata* in the 2 mL/dispenser treatment was 1.50±0.58 individuals at 42 days after planting, while in the 0.25 mL/dispenser and 0.5 mL/dispenser treatments, none were found. The GeO attractant also affects the abundance of *C. inaequalis* ($p<0.001$) (Figure 5.B). The highest abundance was found in the 2 mL/dispenser treatment at all observation times (Figure 5.B).

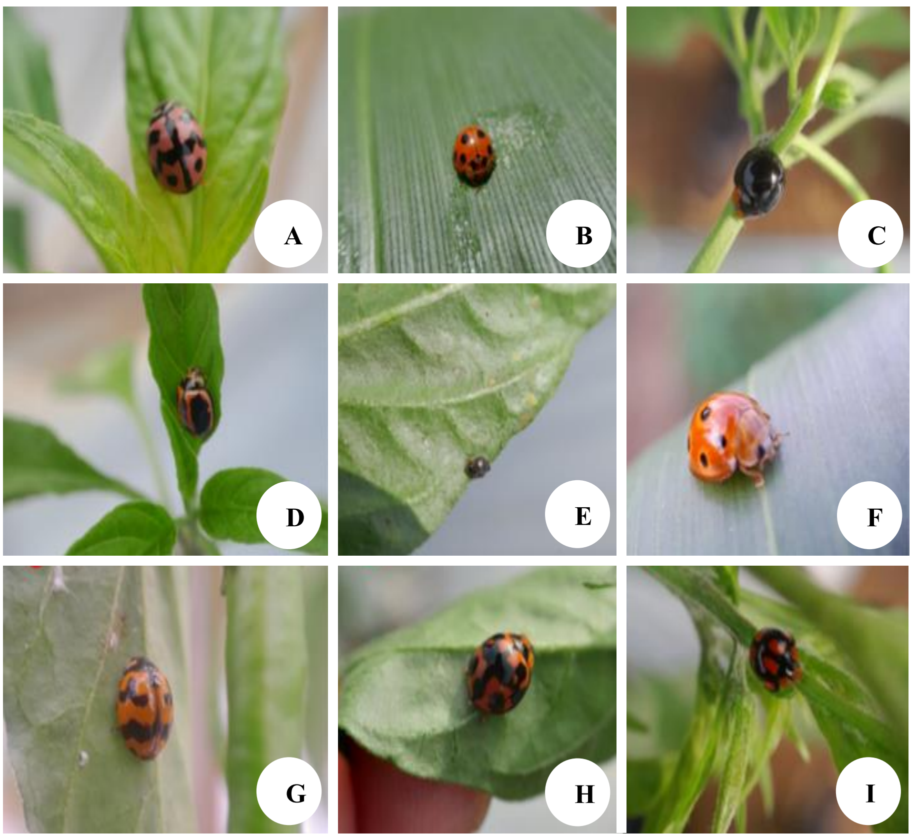
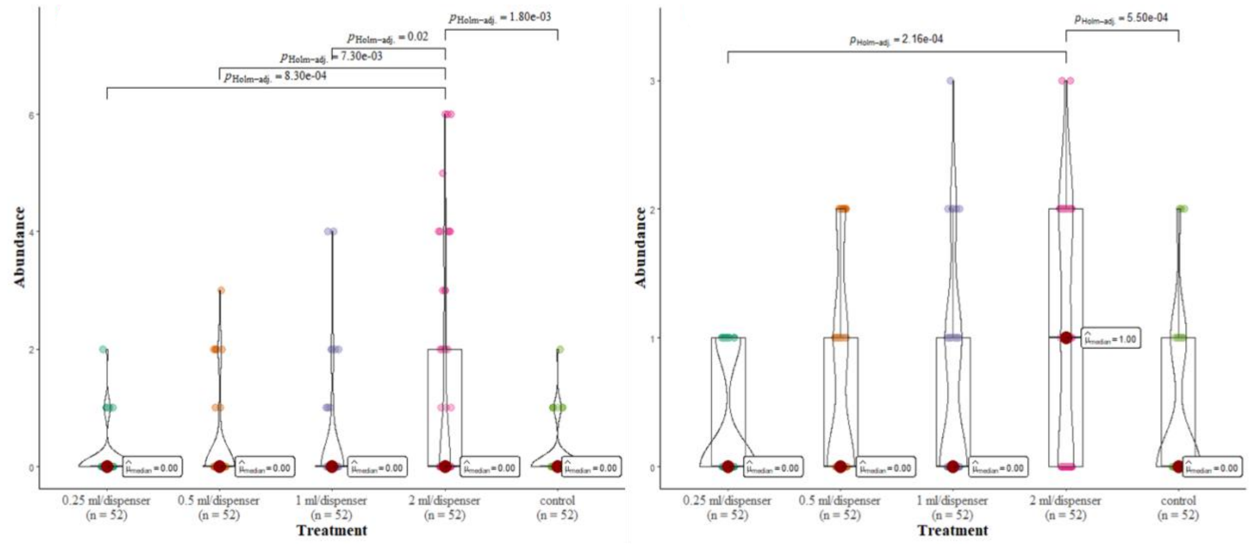
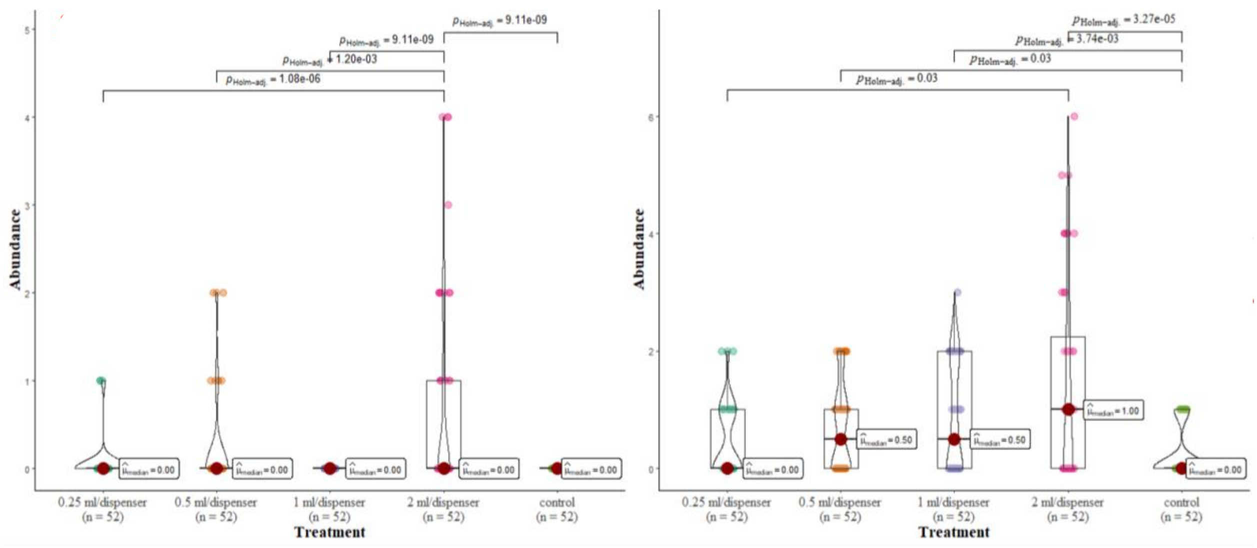


Figure 3. Coccinellids on chili crops: A. *Cheilomenes sexmaculata*, B. *Coelophora inaequalis*, C. *Curinus coeruleus*, D. *Micraspis lineata*, E. *Scymnus* sp., F. *Coccinellidae* sp1, G. *Coccinella transversalis*, H. *Coelophora maculata*, I. *Harmonia decussata*



A B

Figure 4. Violin plot showing abundance of: A. *H. decussata*, B. *M. lineata* at several doses of GeO attractant. *P* holm-adj<0.001

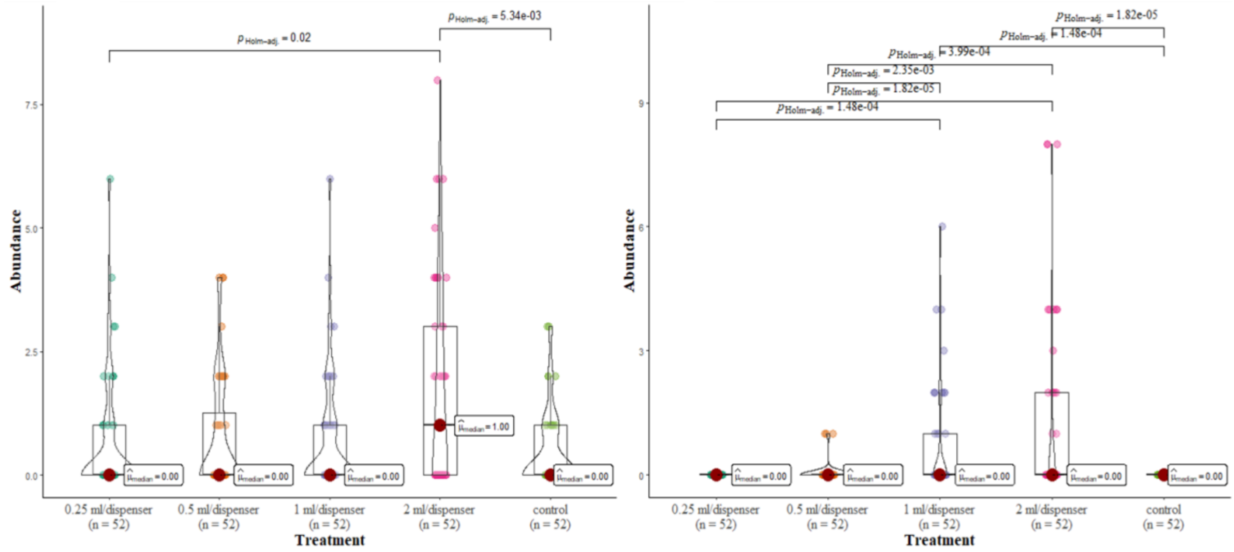


A B

Figure 5. Violin plot showing abundance of: A. *Coelophora maculata*, B. *Coelophora inaequalis* at several doses of GeO attractant. *P* holm-adj<0.001

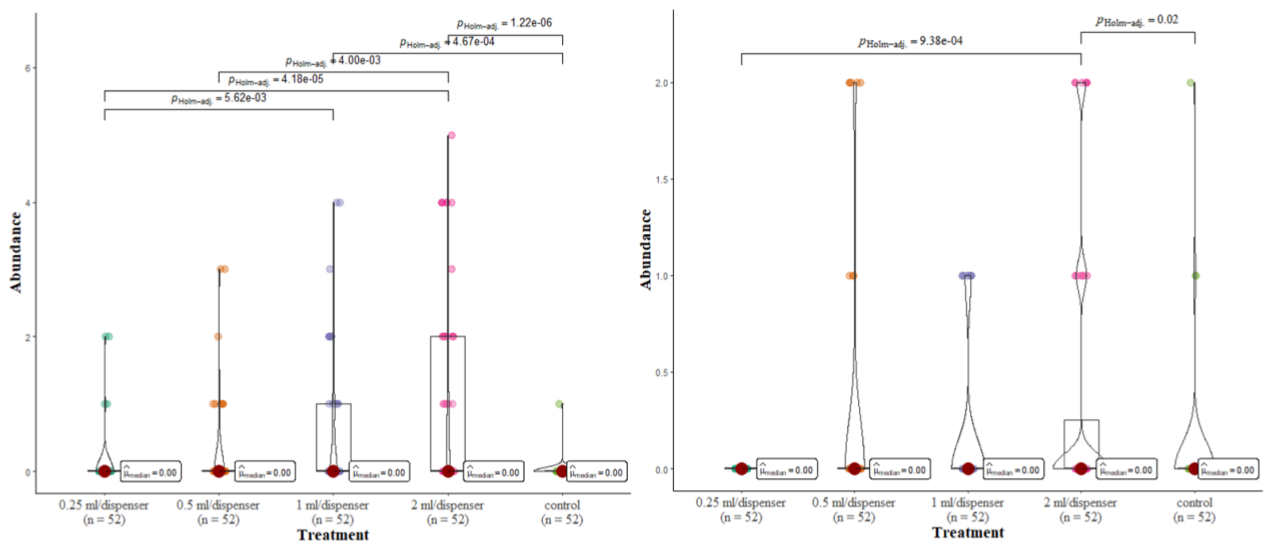
GeO attractants affect the abundance of *Scymnus* sp. (*p*<0.001) (Figure 6.A). The highest abundance was found in the treatment with 2 mL/dispenser, significantly different from the treatment with 0.25 mL/dispenser and without attractant. Still, the 1 mL and 2 mL/dispenser treatments were not significantly different (Figure 6.A). GeO attractants also affect the abundance of *C. coeruleus* (*p*<0.001) (Figure 6.B). The highest abundance was found in the treatment with 2 mL/dispenser, significantly different from the treatments with 0.25 mL/dispenser, 0.5 mL/dispenser and without attractant, but not significantly different from the treatment with 1 mL/dispenser (Figure 6.B).

GeO attractants affect the abundance of *C. transversalis* (*p*<0.001) (Figure 7.A). The highest abundance of *C. transversalis* was found in the treatment with 2 mL/dispenser, which was significantly different from the treatments with 0.25 mL/dispenser, 0.5 mL/dispenser and without attractant, but not significantly different from the abundance in the treatment with 1 mL/dispenser (Figure 7.A). *Cryptolaemus montrouzieri* was a species of coccinellid that is rarely reported in chili crops. The presence of this species in chili crops was an interesting finding. The abundance of the treatment 2 mL/dispenser was significantly different from 0.25 mL/dispenser and without attractant (*p*<0.001) (Figure 7.B). However, it was not significantly different from the treatment of 0.5 mL and 1 mL/dispenser (Figure 7.B).



A B

Figure 6. Violin plot showing abundance of: A. *Scymnus* sp., B. *Curinus coeruleus* at several doses of GeO attractant. *P* holm-adj<0.001



A B

Figure 7. Violin plot showing abundance of: A. *Coccinella transversalis*, B. *Cryptolaemus montrouzieri* at several doses of GeO attractant. *P* holm-adj<0.001

The relationship between the attractants GeO, Coccinellids, *Aphis gossypii* and chili yield

GeO attractants have a significant positive direct relationship with the abundance of coccinellids (Coefficient = 0.99; SE = 0.028; p<0.001) and species richness (Coefficient = 0.76; SE = 0.098; p<0.001) (Figure 8). The abundance of coccinellids has a direct effect that is not significantly negatively suppressive of *A. gossypii* (Coefficient = -0.03; SE = 0.111; P = 0.753), while the richness of coccinellid species has a significant direct effect, negatively suppressing *A. gossypii* (Coefficient = -0.67; SE = 0.223; p<0.01) (Figure 8). The abundance of *A. gossypii* has a significant direct effect, negatively affecting chili yield (Coefficient = -0.65; SE = 0.119; p<0.001). The higher the abundance of *A. gossypii* that attacks chili plants, the less yield there will be.

Discussion

GeO attractants can increase the abundance of *C. sexmaculata*. This finding was different from the previous report. *C. sexmaculata* was not attracted to MeSA synthesis in the plum orchard (Dong and Hwang 2024). *C. sexmaculata* prefers the semiochemical of (+)-3-carene over MeSA in field tests (Srinivas et al. 2024). *C. sexmaculata* is reported to be attracted to the volatiles emitted by plants infested with aphids (Jagdish et al. 2011).

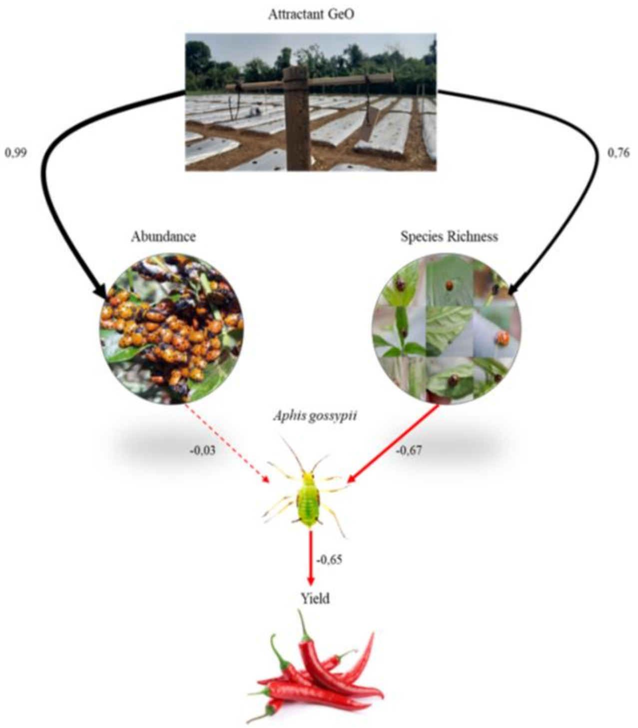


Figure 8. Diagram of the indirect relationship between the attractant application and chili yield

As reported by Hithesh et al. (2024). *C. sexmaculata* shows a much greater interest in the volatile substances emitted from cabbage (*Brassica oleracea*) infested with aphids. This difference may be due to the different composition of GeO attractants compared to MeSA synthesis. GeO not only contains MeSA as the main component, but other compounds that act as attractants, namely caryophyllene (Table 2). The response of insects to attractants is influenced by a combination of compounds, not just a single compound. The interaction between MeSA and caryophyllene may produce a synergistic effect, in which the combined attractiveness of the compounds is greater than the attractiveness of each compound separately. This was an advantage of GeO attractants compared to MeSA synthetic.

GeO attractant was able to attract *C. sexmaculata* and other coccinellids early to the chili crops. *C. sexmaculata* was identified in chili crops 21 days after planting, while in plots without attractants it was identified 28 days after planting. The effective concentration of GeO attractant was 1% with a dose of 2 mL/dispenser. This finding was consistent with several previous studies. The MeSA application can accelerate the visitation of *S. sodalis* (Coleoptera: Coccinellidae), thus reducing the population of *A. gossypii* on cucumber plants (Dong and Hwang 2017). MeSA in GeO functions as an effective signal to attract *C. sexmaculata* to the planting area. The earlier presence of *C. sexmaculata* has the potential to increase the efficiency of *A. gossypii* control in chili plants. *C. sexmaculata* was able to suppress the population of *A. gossypii* before causing damage to chili plants. The ability of *C. sexmaculata* to distinguish the volatiles of infested plants plays an important role in the orientation behavior of *C. sexmaculata* to find aphids (Hithesh et al. 2024).

GeO attractants can also increase the abundance of several other coccinellid species, namely *M. lineata*, *H. decussata*, *C. maculata*, *C. inaequalis*, *Scymnus* sp., *C. coeruleus*, *C. transversalis*, and *C. montrouzieri*. The Coccinellids had previously been reported on chili crops. The abundance of these coccinellids was reported to be low in chili crops.

Aprila et al. (2019) reported *M. lineata* in chili crops in several subdistricts in Kuantan Singingi District. *M. lineata* has also been reported in rice and corn plants (Rahmawasiah et al. 2022). This is related to the behavior of *M. lineata*, which likes the pollen of these two plants. Around the research location, there are several corn fields. The field is thought to be the source of the presence of *M. lineata* before to the chili crops. The GeO attractant application was able to attract *M. lineata* 14 days faster than without attractant. The beetle was found in chili plants 21 days after planting. *M. lineata* was found in the treatment plot of 0.25 mL/dispenser when the chili plants were 28 days old after planting in a plot without attractants, namely 35 days after planting. *M. lineata* preys on *Bemisia tabaci* and *Myzus persicae* on chili plants (Hidayat et al. 2021). Both pests were also identified in chili plants during the research.

The attraction of *H. decussata* to volatile compounds or synthetic attractants has not been widely reported. Some species of the genus *Harmonia* sp. were reported to be attracted to MeSA. The application of MeSA in corn fields increases the abundance of *Harmonia axyridis* (Xu et al. 2024). Yang et al. (2023) also reported the attraction of *Harmonia* sp. to MeSA. *H. axyridis* was also reported to be attracted to 29 volatile oils tested as attractants (Zhao et al. 2020). The similarity of the genus can indicate the potential interest in MeSA volatile compounds. The interaction between the Odorant-Binding Protein (OBP) and odorant is the first step in recognizing chemicals, transporting external odors through the lymph sensillum to the odorant receptors (Pelosi et al. 2018). In *H. axyridis*, the odor-binding protein HaxyOBP5 shows binding affinity with MeSA. Still, it cannot always be used as a definitive reason for concluding that all species in the genus will respond to the same compound identically.

Cheilomenes maculata was a coccinellid species that was naturally low in abundance. Although the abundance of *C. maculata* is low, it is consistently reported in chili crops. *Coelophora inaequalis* has long been reported as a predator of aphids on chili plants. *C. inaequalis* was reported to prey on *Aphis craccivora* and *Rhopalosiphum maidis* (Edde 2022). This aphid species was rarely reported to infest chili plants, but *C. inaequalis* was also reported to prey on several mites. The chili plants at the research site show symptoms of mite infestation. *Polyphagotarsonemus latus* is a mite that has been reported as one of the main pests on chili plants (Kumari 2024). Indirectly, the GeO attractant application, which is aimed at attracting the natural enemies of aphids, also turns out to attract the natural enemies of mites that are pests on chili.

The presence of *Scymnus* sp., *C. coeruleus*, and *C. montrouzieri* has not been widely reported in chili crops. This finding shows that GeO attractant has a broad spectrum of attraction to other coccinellid species. Some species from the Scymninae family were also reported to be attracted to methyl salicylate. Applying MeSA with a concentration of 0.1% increases the abundance of *S. sodalis* in cucumber plants (Dong and Hwang 2017), *Stethorus* sp. in a grape vineyard (Gadino et al. 2012) and *Stethorus punctum picipes* in small-scale field tests (Maeda et al. 2015). In this study, *Scymnus* sp. was first observed on chili plants 42 days after planting, later than the presence of *C. sexmaculata* and *M. lineata*. Previously reported by Dong and Hwang (2017), MeSA can accelerate the visit of *S. sodalis* to reduce the population of *A. gossypii* on cucumber plants. The presence of *Scymnus* sp. in chili plants is an interesting finding, as there have been no reports of the beetle's presence before. Omkar and Pervez (2016) reported the genus *Scymnus*, as a predator of aphids.

The presence of *C. coeruleus* in chili crops is an interesting finding because it has never been reported before. In addition, there has been no report of *C. coeruleus* interest in MeSA and HIPVs. *C. coeruleus* is reported to be abundant on *Hibiscus brackenridgei* to feed on nectar (Krakos et al. 2011). Prey of *C. coeruleus* was also not found in chili plants. *Curinus coeruleus* was reported to prey on several scale insects, *Chrysomphalus aonidum* and *Diaphorina citri*, on citrus plants (Al-Shami and Qureshi 2022), *C. coeruleus* is also reported to *Heteropsylla cubana* on lamtoro plants (Valdés et al. 2020). These pests was not found on chili plants during the experiment. *C. coeruleus* was present on chili crops, presumably as a response to GeO. This finding provides an opportunity to utilize GeO as an attractant to control scale insects in other commodities.

Coccinella transversalis has been widely reported in chili crops. Efendi et al. (2017) and Surya et al. (2020) reported *C. transversalis* in red chili plants in Darussalam District, Aceh Besar and organic chili crops in West Sumatra. *C. transversalis* was reported to be attracted to a 10% concentration of *A. craccivora*-infested cowpea leaf extract (Rakshith et al. 2018). Sinomon (volatiles from cowpea plants) and kairomones (volatiles from aphid bodies) play an important role in the orientation behavior of *C. transversalis* in finding *A. craccivora* on cowpeas (Rakshith et al. 2018). Some *Coccinella* genera were also reported to be attracted to methyl salicylate. The MeSA application can attract *Coccinella septempunctata* in soybean fields (Mallinger et al. 2011), sage orchards (Zarkani and Turanli 2021), and tobacco (Shaolong et al. 2022). *C. septempunctata* is also reported to be attracted to floral volatiles (Zhao et al. 2020). *Cryptolaemus montrouzieri* is reported to be attracted to various volatile compounds emitted by plants, one of which is methyl salicylate (Andrade et al. 2023). This species was also reported as the main predator of the pseudococcidae mealybug (Zim et al. 2023). In addition, *C. montrouzieri* has also been reported to prey on several aphids, namely *M. persicae*, *A. pisum* and *B. tabaci* (Maes et al. 2014). In research, the pest suspected of being the prey of *C. montrouzieri* was *B. tabaci*. *B. tabaci* has been reported as a pest of chili plants and a vector of viral diseases that are difficult to control.

There was a strong and clear relationship between the richness of coccinellid species and the population of *A. gossypii*. The more diverse the coccinellids, the lower the abundance of *A. gossypii*. An increase in the richness of natural enemy species generally strengthens biological control (Katano et al. 2015). In diverse natural enemy communities, prey suppression strength is determined by the net effect of several mechanisms like resource partitioning, indirect interactions, and non-additive effects (Ives et al. 2005). The diversity of natural enemies reinforces prey suppression through resource partitioning, facilitation, positive selection effects, intraguild predation, behavioral interference, and negative selection effects (Jonsson et al. 2017). The number of individual coccinellids does not directly affect *A. gossypii*, but the diversity of coccinellid species has a significant influence. In the biological control of *A. gossypii*, not only is the number of predators important, but also their diversity. The higher diversity of coccinellid species can create more complex interactions in the chili crop ecosystem. Different species of coccinellids may have different feeding preferences, activity times, or predation rates. The presence of several predator species can result in more stable and comprehensive control of *A. gossypii*.

In conclusion, the GeO attractant application can increase abundance and accelerate the presence of *C. sexmaculata* in chili crops. GeO also attracts eight other coccinellid species. The abundance of coccinellid species also increased in the GeO attractant treatment plot. The effective dose of GeO attractant against *C. sexmaculata* and other coccinellids was 2 mL/dispenser. The highest dose shows the best effectiveness The application of GeO attractants, the abundance of coccinellids and *A. gossypii* are directly related to chili yield. GeO attractant can be a new IPM component for managing *A. gossypii* and other pests in chili crops.

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