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# Diamondback moth (*Plutella xylostella*) population, damage, and parasitoids in South Sumatra brassica crops, Indonesia

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**Abstract.** *Herlinda S, Ramadhan MAS, Lau WH, Rindiani DE, Irsan C, Anggraini E, Sari JMP. 2025. Diamondback moth (*Plutella xylostella*) population, damage, and parasitoids in South Sumatra brassica crops, Indonesia. Biodiversitas 26: 6162-6173.* *Plutella xylostella*, diamondback moth can cause up to 100% damage to brassica crops. This study evaluated the presence and performance of *P. xylostella* egg and larval parasitoids, analyzed parasitoid species diversity, and assessed pest populations and associated crop damage. Surveys were conducted in lowland and highland areas across five districts/cities (Lahat City, Pagaralam City, Muara Enim District, Ogan Ilir District, and Banyuasin District), encompassing 13 villages in South Sumatra, Indonesia. Four parasitoid species were identified: *Trichogramma* sp., *Tetrastichus howardi*, *Diadegma semiclausum*, and *Cotesia plutellae*. Egg parasitism was significantly higher during the vegetative stage (48.09%) compared to the generative stage (33.59%) ($P$=0.0054). Similarly, larval parasitism was greater in the vegetative stage (44.35%) than in the generative stage (21.90%) ($P$=0.00013). The highest larval damage occurred in the highlands, particularly Dempo Skyline Village, Pagaralam City (92.10%). The greatest egg population density was observed in Gn. Agung (72.00 eggs per 100 plants), while larval density ranged from 3.33 to 13.00 larvae per 100 plants. Parasitoid species occurred across sites, while *P. xylostella* infestation and feeding damage varied with location. Therefore, strategies to enhance parasitoid effectiveness through conservation and augmentation are necessary to reduce pest populations and protect brassica crops.

**Keywords:** *Brassica juncea*, *Brassica oleracea*, *Cotesia plutellae, Diadegma semiclausum, Tetrastichus howardi*

## INTRODUCTION

Leafy vegetables are crops primarily cultivated for their edible leaves (Sujeewa-Kumari et al. 2022). They are widely grown commercially and possess significant economic importance (Shehzad et al. 2023). Common leafy vegetables include brassica crops, such as pak choi (*Brassica chinensis*), green or Indian mustard (*Brassica juncea*), and lettuce (*Lactuca sativa*) (Rai and Halder 2023). These crops are valued not only for their nutritional and market importance but also for their aesthetic appeal, as their leaves are typically consumed fresh and must meet high visual quality standards. Consumers demand blemish-free, smooth, and pest-free leaves, and even minor nibbling or discoloration can reduce their market value (Ofuya et al. 2023).

Leafy vegetables are highly susceptible to insect pests that cause direct feeding damage and significant yield losses. Notable pests include diamondback moth (*Plutella xylostella*), which attacks *B. chinensis*, *B. juncea*, and *L. sativa* (Machekano et al. 2020), *Chrysodeixis chalcites* (Dionisio and Calvo 2022), *Spodoptera exigua* (Pengsook et al. 2022), *Spodoptera frugiperda* (Nurkomar et al. 2023), and *Lipaphis erysimi* (Dhillon et al. 2022). These pest infestations result in substantial direct losses, with estimated economic impacts of approximately US$4-5 million annually (Shehzad et al. 2023).

To produce smooth, blemish-free leafy green vegetables, growers commonly rely on synthetic insecticides to manage insect pests that feed on these crops (Shehzad et al. 2023). Frequently utilized insecticides contain the active compounds, such as chlorpyrifos, profenofos, and imidacloprid (Bhamdare et al. 2022). However, continuous and indiscriminate use of these chemicals has led to the development of resistance in several pest species (Siddiqui et al. 2023). For instance, *P. xylotella* has developed resistance to chlorpyrifos ethyl, deltamethrin, and spinosad (Agboyi et al. 2016). Pesticide residues are commonly found in vegetable tissue, posing potential risks to food safety and environmental health (Park et al. 2021). The use of chlorpyrifos-based insecticides can also negatively affect beneficial organisms, such as the egg parasitoid *Telenomus remus* (Amaro et al. 2018) and *Cotesia vestalis,* the larval parasitoid of *P. xylostella*, which is highly susceptible to spinosad (Agboyi et al. 2016). As a sustainable alternative, biological control is increasingly recognized as an environmentally friendly and safe strategy for pest management (Prabaningrum and

Moekasan 2020; Ofuya et al. 2023). Biological control of leaf-feeding insect pests can be achieved through the use of natural enemies, such as predators, parasitoids (Prabaningrum and Moekasan 2020) and entomopathogens (Herlinda et al. 2020).

Biological control is effective when natural enemies are able to establish and persist within the ecosystem. Therefore, it is essential to identify and utilize natural enemies that are already present in the field. Previous studies in South Sumatra documented six egg and larval parasitoid species attacking *P. xylostella* in brassica vegetable crops: *Diadegma semiclausum* (Hymenoptera: Ichneumonidae), *Cotesia plutellae* (Hymenoptera: Braconidae), *Oomyzus sokolowskii* (Hymenoptera: Eulophidae), *Tetrastichus* sp. (Hymenoptera: Eulophidae), a ceraphronid wasp (unidentified species), and *Trichogrammatoidea cojuangcoi* (Hymenoptera: Trichogrammatidae) (Herlinda 2005). However, this earlier research did not include information on the population levels of *P. xylostella* (eggs and larvae) or the damage it causes. In 2025, we conducted a follow-up survey to assess the presence of these six parasitoid species in both lowland and highland areas of South Sumatra, and to supplement these records with updated data on *P. xylostella* populations and damage severity. The use of egg parasitoids is particularly advantageous because they target the pest before it reaches the destructive larval stage (Putri et al. 2024). If any pest eggs escape parasitism and hatch, larval or larval-pupal parasitoids can continue the suppression by attacking the emerging larvae (Asmoro et al. 2021). The presence of egg and larval parasitoids in the leafy vegetable ecosystem is expected to synergistically and effectively suppress *P. xylostella*. Egg parasitoids act as the initial line of defense, while larval and pupal parasitoids provide secondary control (Putri et al. 2024). When both groups survive and successfully parasitize their respective host stages, leafy vegetables are better protected from infestation, leading to healthier crops with improved aesthetic quality. This study assessed the presence and performance of egg and larval parasitoids of *P. xylostella*, analyzed their species diversity, and determined the pest's population levels (eggs and larvae) along with the associated crop damage.

## MATERIALS AND METHODS

### Study area

The survey was conducted in vegetable brassica crop centers in South Sumatra Province, Indonesia, covering lowlands (<20 m below sea level) to highlands (>700 m bsl). Muara Enim, Ogan Ilir, and Musi Banyuasin Districts were chosen for the lowlands, and Lahat and Pagaralam Cities for the highlands (Figure 1). Talang Taling (Lat -3.23909°, Long 104.505854°) in Muara Enim District and Talang Buluh (Lat -2.902583°, Long 104.760523°) in Musi Banyuasin District were chosen. In Ogan Ilir District, the selected villages were Bakung (Lat-3.215109°, Long 104.534847°) and Pulau Semambu (Lat -3.163332°, Long 104.688679°). In Lahat District, the selected villages were Guru Agung (Lat-3.989192°, Long 103.232055°) and Jarai (Lat -3.950114°, Long 103.201017°). In Pagaralam City, the selected villages were Jangkar Mas Village (Lat -4.041008°, Long 103.227731°), Pagar Wangi (Lat -4.046917°, Long 103.228593°), Tanjung Agung (Lat -4.045344°, Long 103.242709°), Gn. Dempo (Lat -4.021559°, Long 103.165313°), Dempo Skyline (Lat -4.022107°, Long 103.157002°), Jokoh (Lat -4.125938°, Long 103.260657°), and Reba Tinggi (Lat -4.04859°, Long 103.242319°). The village was selected as the observation site because it was a center for brassica vegetable production and provides approximately 1 hectare per location suitable establishing survey plots. The plots consisted of white mustard (*Brassica pekinensis*), cabbage (*Brassica oleracea*), and green mustard (*B. juncea*) (Table 1). The sampled plants represented both generative and vegetative growth stages.

**Table 1.** Survey locations and vegetable brassica crop samples

| Survey locations and its district/city | Altitude (m asl) | Coordinate | Crop species | Crop stages (ages) |
|---|---|---|---|---|
| Guru Agung, Lahat District | 783 | Lat -3.989192°, Long 103.232055° | White mustard | Generative (5 weeks) |
| Jangkar Mas, Pagaralam City | 801 | Lat -4.041008°, Long 103.227731° | Cabbage | Vegetative (6 weeks) |
| Pagar Wangi, Pagaralam City | 811 | Lat -4.046917°, Long 103.228593° | Green mustard | Generative (7 weeks) |
| Tj. Agung, Pagaralam City | 736 | Lat -4.045344°, Long 103.242709° | Cabbage | Generative (7 weeks) |
| Gn. Dempo, Pagaralam City | 1542 | Lat -4.021559°, Long 103.165313° | Cabbage | Generative (8 weeks) |
| Dempo Skyline, Pagaralam City | 1826 | Lat -4.022107°, Long 103.157002° | Cabbage | Generative (13 weeks) |
| Jokoh, Pagaralam City | 1114 | Lat -4.125938°, Long 103.260657° | Cabbage | Generative (10 weeks) |
| Jarai, Lahat District | 747 | Lat -3.950114°, Long 103.201017° | White mustard | Vegetative (5 weeks) |
| Reba Tinggi, Pagaralam City | 749 | Lat -4.04859°, Long 103.242319° | Green mustard | Generative (8 weeks) |
| Pulau Semambu, Ogan Ilir District | 10 | Lat -3.163332°, Long 104.688679° | White mustard | Vegetative (4 weeks) |
| Bakung, Ogan Ilir District | 17 | Lat -3.215109°, Long 104.534847° | White mustard | Vegetative (5 weeks) |
| Talang Buluh, Banyuasin District | 10 | Lat -2.902583°, Long 104.760523° | White mustard | Generative (7 weeks) |
| Talang Taling, Muara Enim District | 14 | Lat -3.23909°, Long 104.505854° | White mustard | Vegetative (5 weeks) |

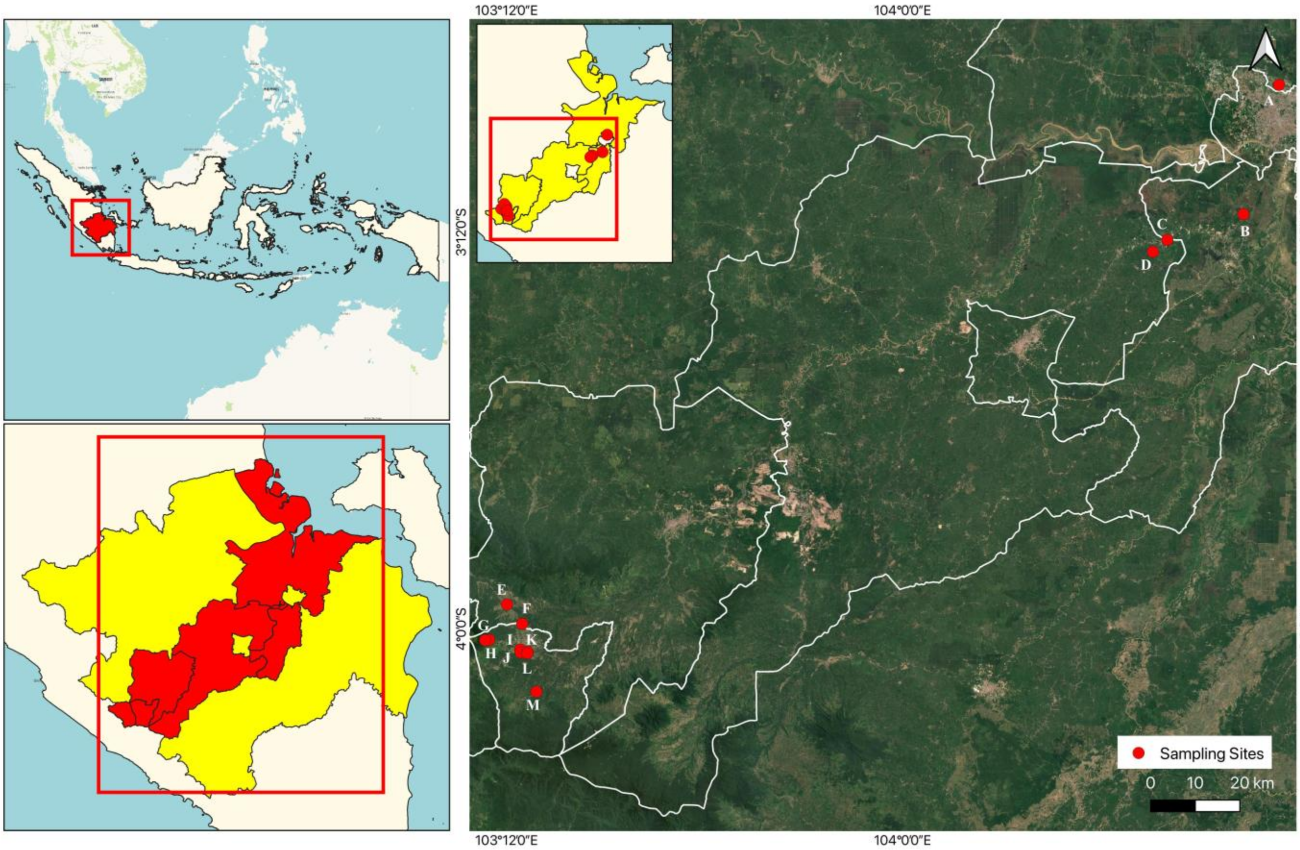

**Figure 1.** Locations for sampling sites of *Plutella xylostella* population, damage, and its parasitoids in South Sumatra, Indonesia. A: Talang Buluh, B: Pulau Semambu, C: Bakung, D: Talang Taling, E: Jarai, F: Guru Agung, G: Dempo Skyline, H: Gn. Dempo, I: Jangkar Mas, J: Pagar Wangi, K: Tj. Agung, L: Reba Tinggi, M: Jokoh

### Sampling and identification of egg and larval parasitoids of *Plutella xylostella*

The selection of sampling sites was performed using purposive criteria based on (i) the presence of actively cultivated brassica crops, (ii) accessibility for repeated sampling, and (iii) representation of both lowland and highland agroecosystems across South Sumatra. Villages were chosen only if they maintained ≥1 ha of continuous brassica cultivation during the survey period, ensuring sufficient host availability for *P. xylostella* and its parasitoids. Seasonality was considered because the survey took place during the dry-to-wet transition period (May-August 2025), when Brassica planting is continuous and pest pressure is typically high. This period corresponds to peak vegetative growth for most brassica fields in both lowland and highland regions.

Purposive sampling was used to collect *P. xylostella* eggs and larvae in order to determine parasitizing rates by their parasitoids. Eggs with a green color and an estimated age of 2-3 days were selected. Greenish-yellow eggs were not taken because they had only recently been laid by the female *P. xylostella* and had a low parasitic potential. Larval parasitoid typically parasitize second instar larvae (the host stage parasitized); thus, third and fourth instar larvae of *P. xylostella* were chosen as samples because they were expected to be parasitized, while first and second instar larvae were excluded (Kahuthia-Gathu et al. 2017). Choosing the appropriate larval instar for parasitoid sampling could result in accurate parasitism estimates. Sample eggs were placed in test tubes (Ø: 1.2 cm, height: 7.5 cm) and labeled with sampling time, location, and plant species. The eggs and larvae from the samples were taken to the laboratory to be observed during their development. Egg samples from each subplot (replication) were collected in separate test tubes. The egg morphology was observed for color changes, and the number of hatched eggs and emerging parasitoids were recorded daily. Larval samples from each subplot were collected in separate plastic cups (Ø 6.5 cm, height 4.6 cm). The plastic cups were lined with tissue paper to absorb excess moisture and closed with cups containing a fine muslin cloth to allow for ventilation. The larvae were fed pakchoi leaves, which were replaced on a daily basis with fresh leaves until the parasitoids or *P. xylostella* pupae emerged. *P. xylostella* larvae were monitored on a daily basis for behavioral changes that could distinguish parasitized from healthy hosts. Parasitoids emerging from the larvae were monitored and recorded until adult parasitoids emerged, the larvae died, or *P. xylostella* adults emerged. The parasitoid adults and *P. xylostella* adults emerged were counted to determine the parasitization rate of *P. xylostella*. The parasitism percentage was calculated by dividing the number of emerged parasitoids by the total number of parasitoids, as well as the number of *P. xylostella* adults that survived after rearing (Syed et al. 2018). The adults were then examined for morphology. The emerging parasitoid adults were placed in a vial bottle (5 mL) containing 70% alcohol, which adapted the method (Herlinda et al. 2023). Then, the parasitoid's morphology was examined with an Olympus SZ51 Zoom Stereo Microscope at 30x magnification and photographed with an Optilab Advance Plus Sony IMX577. Dr. Chandra Irsan, an insect taxonomist at Universitas Sriwijaya, identified the collected parasitoids. The morphological identification process is based on wing venation, thorax, antennal flagella, abdomen, legs, and egg parasitoids, which are identified using the guide of Alba (1988), while larval and larva-pupa parasitoids are identified using the keys of (Herlinda et al. 2023; Saleh et al. 2023; Shen et al. 2023). All parasitoids were identified solely based on morphological characters using standard taxonomic keys (Alba 1988; Herlinda et al. 2023; Saleh et al. 2023; Shen et al. 2023). Molecular identification (e.g., COI barcoding) was not performed in this study; therefore, the species determinations rely entirely on morphology.

### Observation of *Plutella xylostella* population and infestation

*Plutella xylostella* population and damage observations were carried out on the same plots that were used to observe egg and larval parasitoids. A 100-meter line transect was used to conduct these population and attack observations (Herlinda 2005). If the plot was less than 100 m long, sampling was conducted in the original direction; however, the example crops rows differed from the 5 m spacing between rows. Each plot ranged in size from 0.1 to 1 ha, with three subplots for replications. The population and infestation of *P. xylostella* were observed and sampled on 100 example plants from each subplot, for a total of at least 300 plants per location or plot. To estimate the larval populations of *P. xylostella*, 100 plants were randomly selected from each sub-plot and examined for the presence of various stages of *P. xylostella* larvae. The number of larvae per plant was directly observed and counted to estimate larval population density (Navik et al. 2019). *P. xylostella* damage to vegetable brassica crops was physically assessed once per location by observing for symptoms on leaves. A hundred plants were randomly evaluated using a visual damage method (visual scoring) of Kahuthia-Gathu et al. (2017).

### Data analysis

Data on egg and larval parasitizing rates, *P. xylostella* population density, and infestation severity were analyzed following verification of statistical assumptions. Normality was assessed using the Shapiro-Wilk test, and homogeneity of variance was evaluated using Levene's test. Data were arcsine-transformed to meet the assumptions of normality and homogeneity prior to conducting one-way Analysis of Variance (ANOVA). Mean separations were performed using Tukey's Honestly Significant Difference (HSD) test, and results are presented as the average of the original (untransformed) data. Diversity of parasitoids was analyzed at two levels, namely among locations and among species. For the location-based analysis, species diversity was calculated following (Magurran 2004), including abundance per 100 plants, Shannon-Wiener diversity index (H′), evenness (E), and dominance (D). Parasitoid counts from the three field replications at each site were pooled, and the proportion of each species was used to compute $H' = -\Sigma\ p_i \ln p_i$ (Shannon and Weaever 1963), evenness using $E = H'/\ln S$ (Pielou 1966), and dominance using Simpson's index $D = \Sigma\ p_i^2$ (Simpson 1949). These diversity values were displayed as bar charts to compare variation among sampling locations. For the species-based analysis, diversity metrics (mean abundance, H′, E, and dominance) of the four parasitoid species (*C. plutellae*, *D. semiclausum*, *T. howardi*, and *Trichogramma* sp.) were statistically compared. Differences among species were tested using one-way ANOVA, followed by Tukey's HSD when significant effects were detected; non-parametric alternatives (Kruskal-Wallis and Dunn's post-hoc) were applied when assumptions were not met. Group differences were visualized using boxplots, with different letters indicating statistically significant groupings. Principal Component Analysis (PCA) was conducted to identify major patterns in parasitoid community structure and to visualize how sampling locations differed in species composition. The analysis was based on a data matrix containing the mean abundance of each parasitoid species (*Trichogramma* sp., *Tetrastichus howardi*, *D. semiclausum*, and *C. plutellae*) at every sampling site, where each site represented one observation (row) and each species represented one variable (column). The resulting principal components captured the greatest sources of variation in the dataset and were presented in a biplot. In this biplot, locations with similar parasitoid assemblages cluster closely together, while species that contribute most strongly to differences among sites appear as longer vectors. Through this approach, the PCA effectively illustrated the main gradients in parasitoid community composition across districts. Pearson's chi-squared test was employed to compare parasitizing rates between vegetative and generative plant stages. All statistical analyses were conducted in RStudio (Version 1.4.1106; RStudio PBC, Boston, MA, USA).

## RESULTS AND DISCUSSION

### *Plutella xylostella* damage

*Plutella xylostella* laid its eggs on both the underside and upper surface of brassica leaves, resulting in larvae capable of feeding on various parts of the leaves (Figure 2.A). Larvae were often found on the undersides of leaves (Figure 2.B). Early instar larvae window-like spots on the leaves (windowing symptoms), creating transparent patches where parenchyma tissue was consumed from the underside of the leaves, leaving only the upper epidermis intact (Figure 2.C). Adult larvae consumed the entire leaf tissue, leaving only the main veins and producing irregularly shaped holes distributed across the leaf surface. Feeding occurred on plants in both vegetative and generative growth stages (Figure 2.D-E). In cabbage, larvae also fed on the leaves and the outer layers of the developing head, often accompanied by visible frass deposits (Figure 2.F).

The survey results revealed that *P. xylostella* infestations were present at all sampling sites, across both lowland and highland regions of South Sumatra. The mean incidence of larval infestation differed significantly among locations ($P<0.0001$) (Figure 3). The highest infestation levels were recorded in the highland area of Pagaralam City, particularly in Dempo Skyline Village (92.10%), followed by Jokoh (74.01%) and Gn. Dempo Villages (65.41%). In contrast, the lowest infestation levels occurred in mid- to lowland areas, with Guru Agung Village in Lahat District showing the lowest incidence (42.88%), followed by Pulau Semambu in Ogan Ilir District (45.27%) and Pagar Wangi in Pagaralam City (45.21%). Although infestation levels were generally higher in the highlands, *P. xylostella* occurred across all altitudes. This study did not test altitude as a predictor variable; therefore, no causal inference regarding altitudinal effects can be made.

**Figure 2.** Symptoms of *Plutella xylostella* larvae attack on brassica crops: A: Eggs under leaf surface, B: Larvae eating leaves, C: Affected leaves turning transparent, D: Larvae attacking cabbage in the vegetative stage, E: Larvae attacking cabbage in the generative phase, F: Black larval excrement

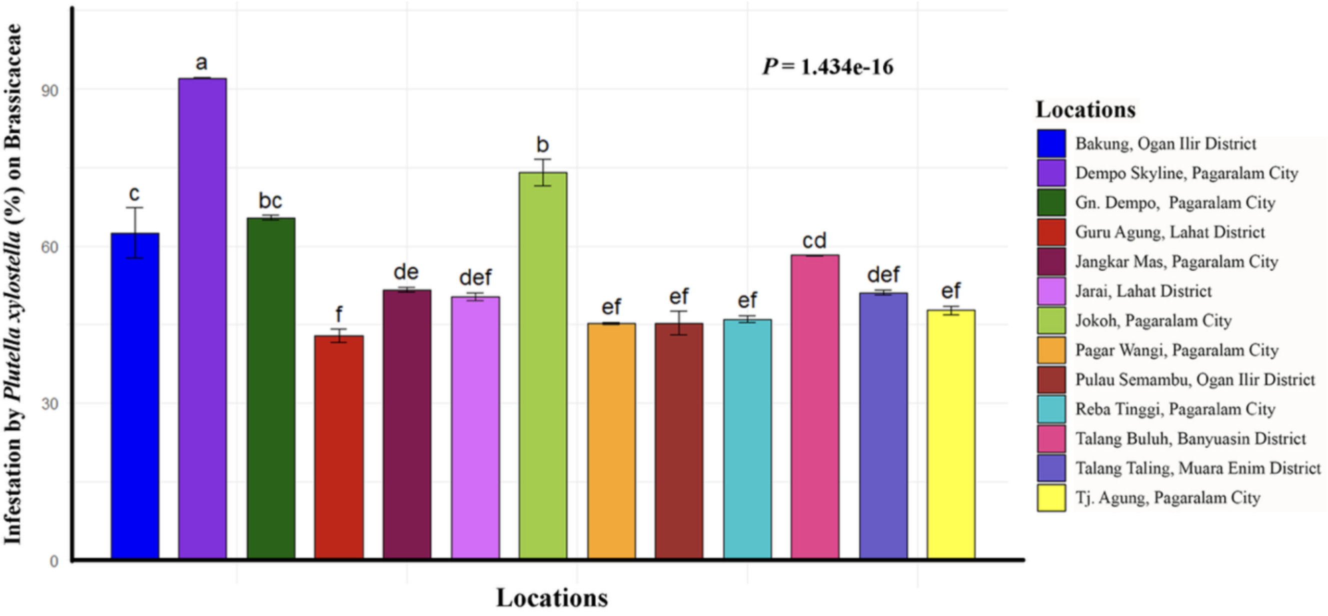

**Figure 3.** Percentage of damage caused by *Plutella xylostella* larvae on brassica crops in South Sumatra, Indonesia

## Population of *Plutella xylostella* eggs and larvae

A female *P. xylostella* adult laid her eggs on the leaf surface one at a time, but close enough together to form clusters. The number of egg clusters and population density of eggs laid by females on 100 plants differed significantly between locations (*P*<0.0001) (Figure 4). The highest number of egg clusters was found in the highland area of Jokoh Village (30.33 egg clusters), although this value was not significantly different from seven other villages (Pagar Wangi, Reba Tinggi, Tj. Agung, Jarai, Dempo Skyline, Gn. Dempo, and Jangkar). In contrast, the lowest number of egg clusters were found in the lowland areas, particularly Pulau Semambu, Talang Buluh, Talang Taling, and Bakung Villages. A similar trend was observed for egg population density, with the highest density recorded in the highlands, specifically in Gn. Agung (72.00 eggs per 100 plants). Larval density ranged from 3.33 to 13.00 larvae per 100 plants and also varied significantly across locations (*P*<0.0001) (Figure 5).

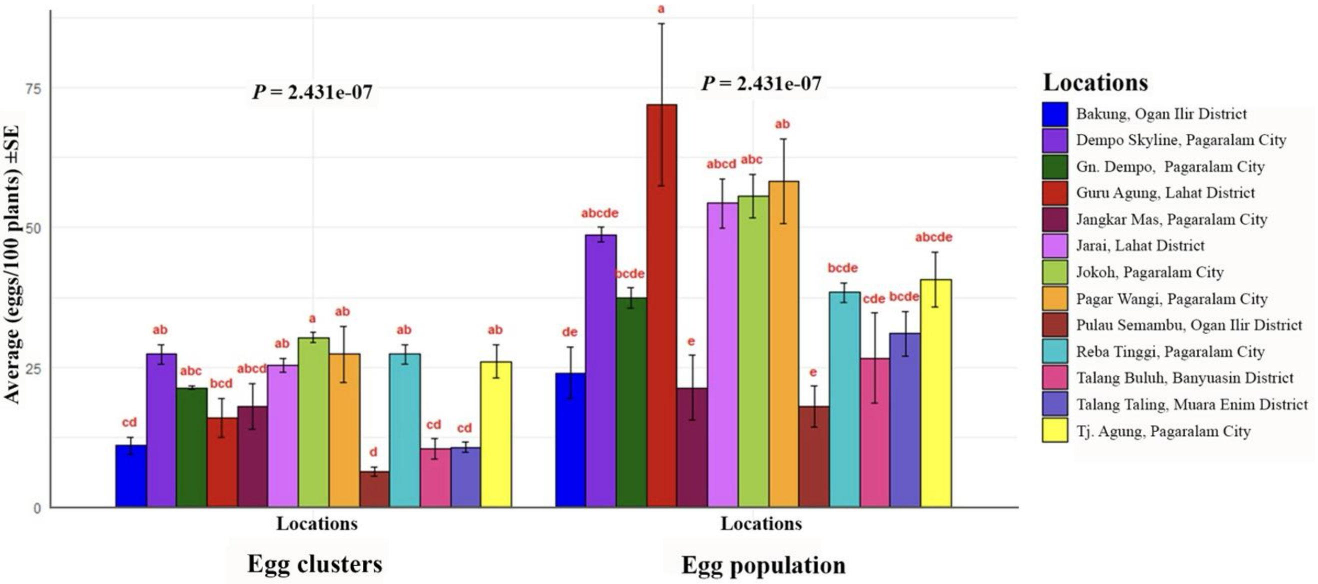

**Figure 4.** Number of egg clusters and egg population density of *Plutella xylostella* in brassica crops in South Sumatra, Indonesia

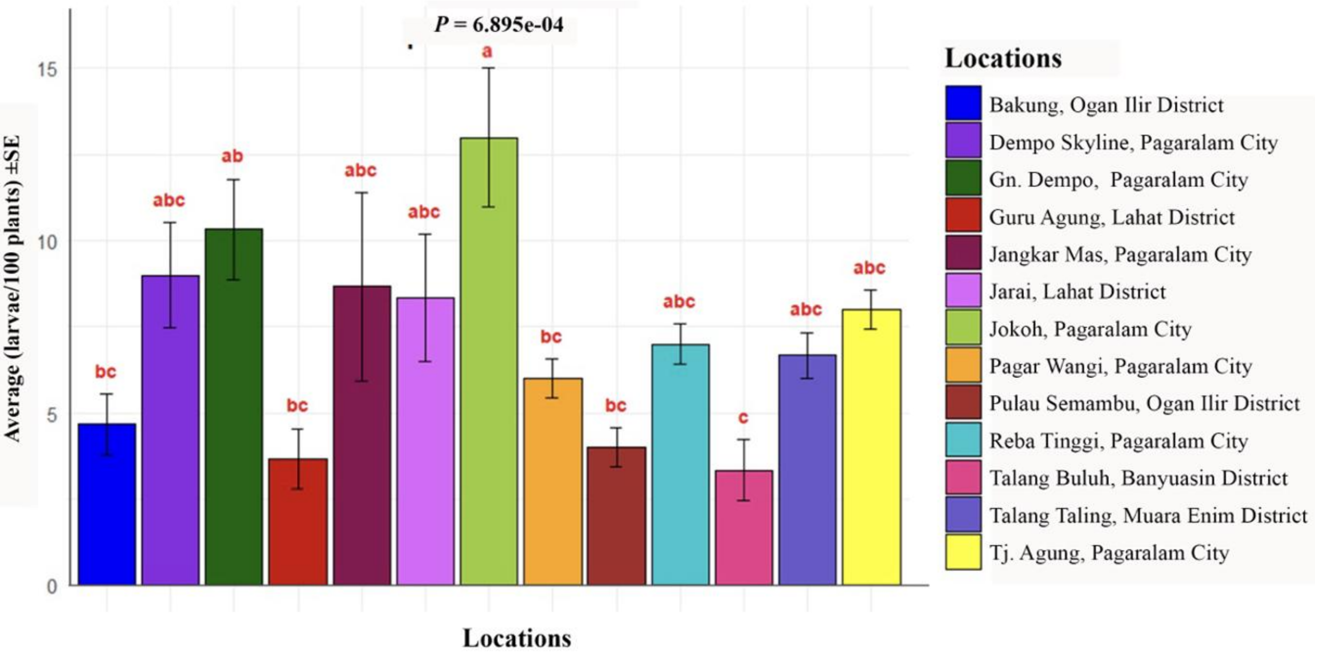

**Figure 5.** Larval population density of *Plutella xylostella* in brassica crops in South Sumatra, Indonesia

### Abundance and species diversity of egg and larval parasitoids of *Plutella xylostella*

Four parasitoid species of *P. xylostella* were recorded in this study, one egg parasitoid and three larval parasitoids (Figure 6). The egg parasitoid identified was *Trichogramma* sp. (Hymenoptera: Trichogrammatidae), while the larval parasitoids were *T. howardi* (Hymenoptera: Eulophidae), *D. semiclausum* (Hymenoptera: Ichneumonidae), and *C. plutellae* (Hymenoptera: Braconidae). Egg parasitism rates differed significantly between plant growth stages, with a higher rate observed during the vegetative stage (48.09%) compared to the generative stage (33.59%) (P: 0.0054) (Table 2). Similarly, larval parasitism was significantly higher in the vegetative stage (44.35%) than in the generative stage (21.90%) (*P*=0.00013).

Parasitism rates varied significantly among locations in the highlands (*P*<0.0001). The highest egg parasitism occurred in Pagar Wangi Village (87.77%), which did not differ significantly from Jangkar Mas, Jarai, Guru Agung, Gn. Dempo, Reba Tinggi, and Jokoh (Table 3). In contrast, lowland areas such as Pulau Semambu and Bakung exhibited lower egg parasitism rates. A similar trend was observed for larval parasitism (*P*=0.00354). Highland locations, including Jarai, Reba Tinggi, and Tj. Agung, showed high larval parasitism rates (79.89-93.65%), whereas no larval parasitism was recorded at lowland sites such as Pulau Semambu and Bakung.

The most common parasitoid detected was *Trichogramma* sp., which was found in both the highland and lowland regions of South Sumatra. The highest abundance of egg parasitoids was recorded in Pagar Wangi (84.00 individuals/100 plants), although this was not significantly different (*P*<0.0001) from the abundances observed in Jarai, Reba Tinggi, G. Dempo, Guru Agung, Jangkar Mas, and other highland locations (Table 4). *Plutella xylostella* was parasitized by four species: *Trichogramma* sp. (Figure 6.A), *T. howardi* (Figure 6.B), *D. semiclausum* (Figure 6.C), and *C. plutellae* (Figure 6.D). Overall abundance patterns indicated that *Trichogramma* sp. was the most dominant parasitoid species across all sampling locations (Figure 7).

The PCA showed distinct variation in parasitoid community composition among districts, with dim1 (56.2%) and dim2 (24.7%) explaining most of the observed differences (Figure 8). Districts on the positive side of dim1, Banyuasin and Ogan Ilir, were primarily associated with *D. semiclausum*, whereas districts on the negative side, Pagaralam City and Lahat District, ere more strongly influenced by *Trichogramma* sp., *T. howardi*, and *C. plutellae*. Field data were consistent with these ordination patterns: *Trichogramma sp.*, *T. howardi*, and *D. semiclausum* were dominant in the highland district of Pagaralam, while *C. plutellae* was most strongly associated with Lahat, although it also occurred in lowland areas such as Talang Buluh Village. Altitudinal patterns further indicated that *D. semiclausum* and *T. howardi* were restricted to highland habitats, whereas *C. plutellae* was distributed across both highland and lowland regions of South Sumatra.

The diversity metrics of *P. xylostella* parasitoids varied significantly among species (Figure 9). The mean number of individuals differed markedly (*P*=1.7e-05), with *Trichogramma* sp. exhibiting the highest abundance, followed by *T. howardi*, *D. semiclausum*, and *C. plutellae*. Shannon-Wiener diversity (H') also varied significantly among species (P: 0.0051), where *Trichogramma* sp. showed the highest diversity value, while *D. semiclausum* had the lowest. Evenness (J') differed significantly across species (*P*=0.0076); *C. plutellae* exhibited the greatest evenness, whereas the other three species showed relatively lower and comparable values. In contrast, dominance did not differ significantly among parasitoid species (*P*=0.11), although *D. semiclausum* tended to show higher dominance compared with the others.

**Table 2.** The rate of parasitizing of *Plutella xylostella* eggs and larvae in the vegetative and generative stages in brassica crops

| Brassica growing stage | Egg parasitism rates (%) | Larval parasitism rates (%) |
|---|---|---|
| Vegetative | 48.09a (n: 1154) | 44.35a (n: 181) |
| Generative | 33.59b (n: 446) | 21.90b (n: 278) |
| $\chi^2$ stats | 7.72* | 17.88* |
| *P*-value | 0.0054 | 0.00013 |

Note: Data denoted by identical letters within the same column exhibited no significant differences (α: 0.05) according to the Pearson's Chi-squared test, where n represents the number of samples (eggs or larvae) collected. Original data presented in this table were transformed using Arcsin transformation prior to statistical analysis

**Table 3.** The rate of parasitizing of *Plutella xylostella* eggs and larvae in brassica crops in South Sumatra, Indonesia

| Village, city/district | Egg parasitism rates (%) | Larval parasitism rates (%) |
|---|---|---|
| Guru Agung, Lahat District | 60.98abc (n: 216) | 21.67ab (n: 11) |
| Jangkar Mas, Pagaralam City | 70.87ab (n: 64) | 4.76ab (n: 26) |
| Pagar Wangi, Pagaralam City | 87.77a (n: 175) | 59.52ab (n: 18) |
| Tj. Agung, Pagaralam City | 21.96cde (n: 124) | 79.89ab (n: 24) |
| Gn. Dempo, Pagaralam City | 52.63abcd (n: 112) | 36.15ab (n: 31) |
| Dempo Skyline, Pagaralam City | 38.49bcd (n: 146) | 41.87ab (n: 27) |
| Jokoh, Pagaralam City | 45.16abcd (n: 186) | 18.89ab (n: 39) |
| Jarai, Lahat District | 67.07abc (n: 136) | 93.65a (n: 25) |
| Reba Tinggi, Pagaralam City | 55.81abc (n: 115) | 80.16ab (n: 21) |
| Pulau semambu, Ogan Ilir District | 8.06de (n: 54) | 0.00b (n: 12) |
| Bakung, Ogan Ilir District | 1.11e (n: 72) | 0.00b (n: 14) |
| Talang Buluh, Banyuasin District | 21.93cde (n: 80) | 16.67ab (n: 10) |
| Talang Taling, Muara Enim District | 20.84cde (n: 93) | 11.11ab (n: 20) |
| F-value | 9.77* | 3.51* |
| P-value | $7.94\times10^{-7}$ | $3.54\times10^{-3}$ |
| HSD value (0.05) | 0.55 | 89.70 |

Note: Data labeled with the same letter in the same column are not significantly different from each other (α: 0.05) according to Tukey's honestly significant test. Original data presented in this table were transformed using Arcsin transformation prior to statistical analysis

**Table 4.** Abundance of *Plutella xylostella* egg and larval parasitoids in brassica crops in South Sumatra, Indonesia

| **Village, city/district** | **Abundance (individuals/100 plants)** | | | |
|---|---|---|---|---|
| | ***Trichogramma* sp.** | ***Tetrastichus howardi*** | ***Diadegma semiclausum*** | ***Cotesia plutellae*** |
| Guru Agung, Lahat District | 38.00abc | 0.00b | 0.00b | 3.00 |
| Jangkar Mas, Pagaralam City | 38.00abc | 0.00b | 0.00b | 1.00 |
| Pagar Wangi, Pagaralam City | 84.00a | 6.00ab | 0.00b | 4.00 |
| Tj. Agung, Pagaralam City | 24.00abc | 16.00a | 0.00b | 3.00 |
| Gn. Dempo, Pagaralam City | 39.00abc | 0.00b | 12.00a | 0.00 |
| Dempo Skyline, Pagaralam City | 17.00abc | 0.00b | 9.00a | 1.00 |
| Jokoh, Pagaralam City | 22.00abc | 0.00b | 5.00ab | 3.00 |
| Jarai, Lahat District | 60.00ab | 21.00a | 0.00b | 4.00 |
| Reba Tinggi, Pagaralam City | 44.00abc | 15.00a | 0.00b | 2.00 |
| Pulau semambu, Ogan Ilir District | 0.00c | 0.00b | 0.00b | 0.00 |
| Bakung, Ogan Ilir District | 0.00c | 0.00b | 0.00b | 0.00 |
| Talang Buluh, Banyuasin District | 6.00bc | 0.00b | 0.00b | 1.00 |
| Talang Taling, Muara Enim District | 15.00abc | 0.00b | 0.00b | 3.00 |
| F-value | 4.03* | 7.54* | 5.06* | 1.02ns |
| P-value | $1.43 \times 10^{-3}$ | $9.24 \times 10^{-6}$ | $2.67 \times 10^{-4}$ | 0.46 |
| HSD value (0.05) | 4.07 | 1.83 | 1.48 | - |

Note: ns: Not significant; *: Significant difference. Values in columns followed by the same letter are not significant at $P<0.05$ according to Tukey's honestly significant test. Original data presented in this table were transformed using Arcsin transformation prior to statistical analysis

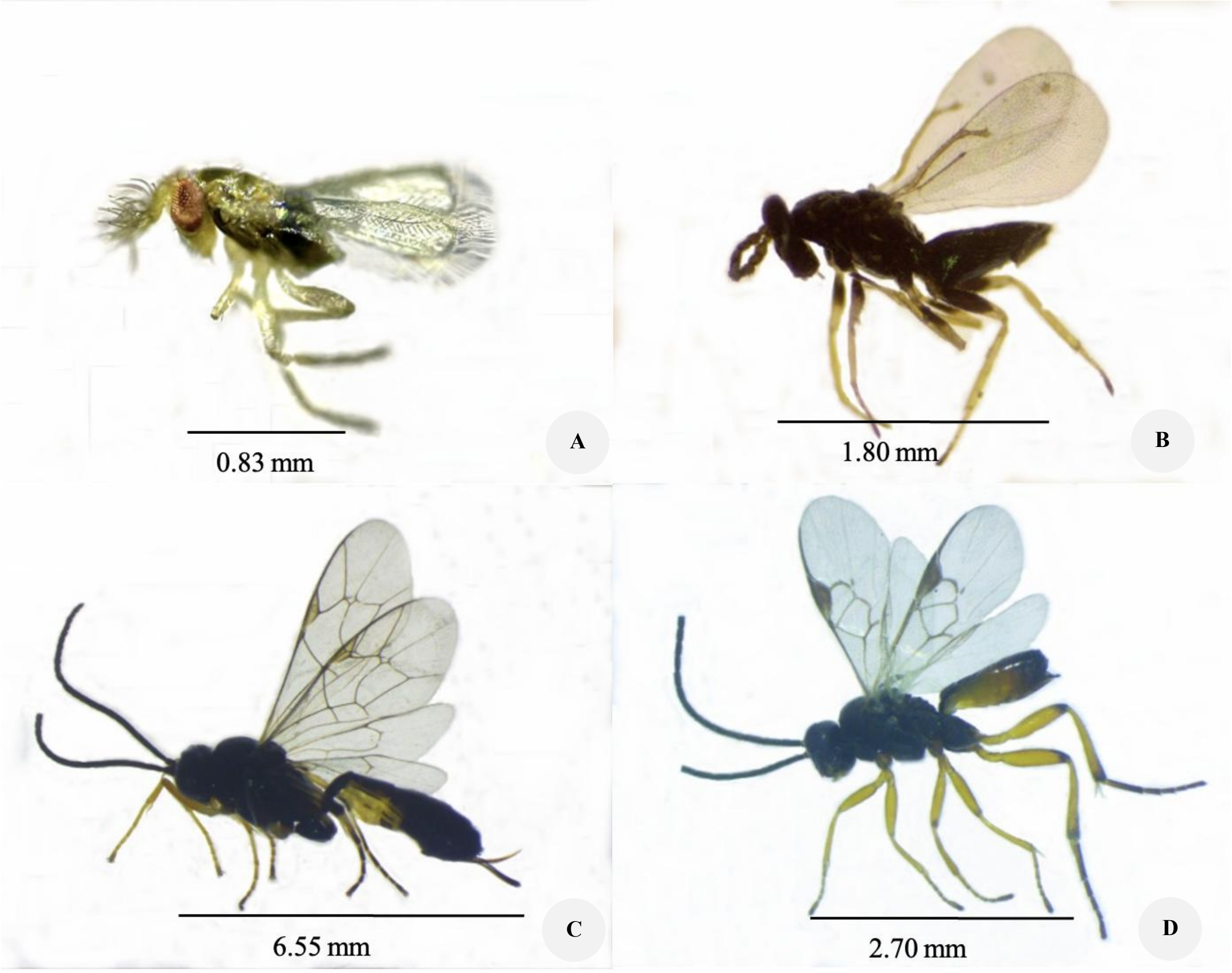

**Figure 6.** *Plutella xylostella* parasitoid species: A: *Trichogramma* sp., B: *Tetrastichus howardi*, C: *Diadegma semiclausum*, D: *Cotesia plutellae*

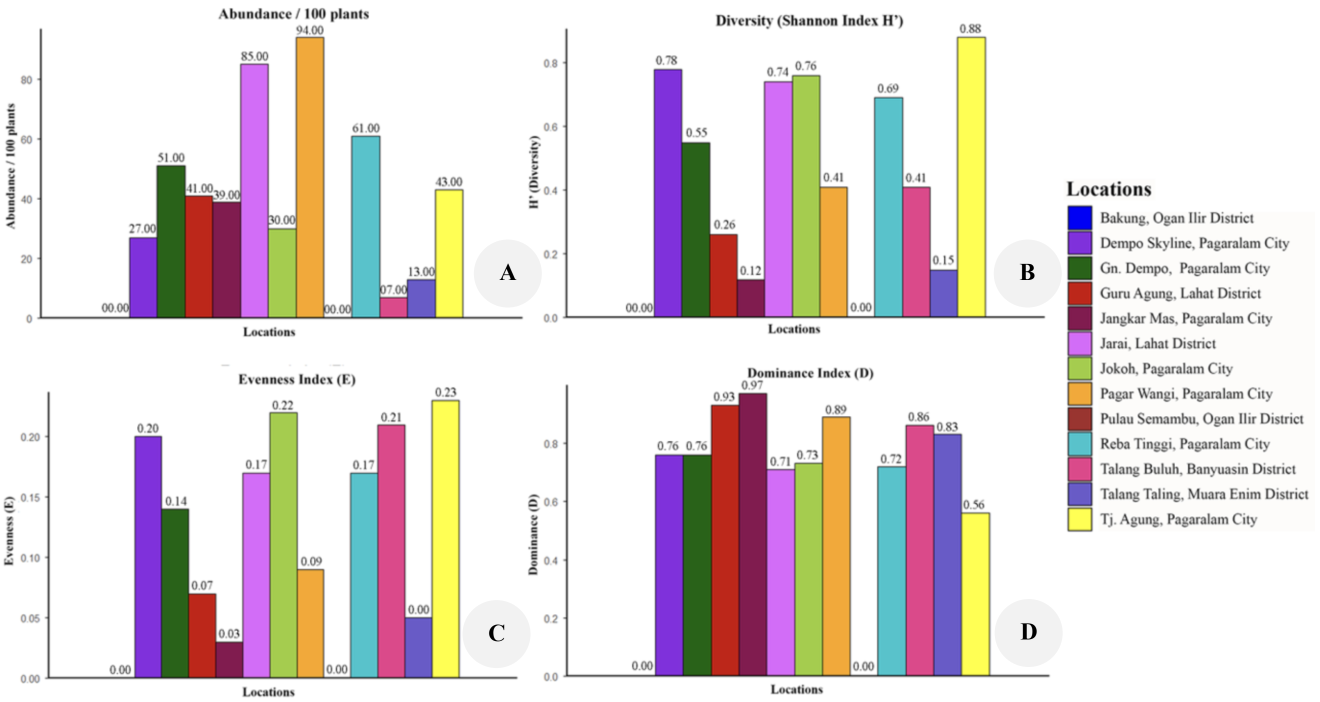

**Figure 7.** Diversity metrics of *Plutella xylostella* parasitoid species in South Sumatra: A: Abundance, B: Shannon-Wiener diversity index H', C: Evenness Pielou J', D: Dominance

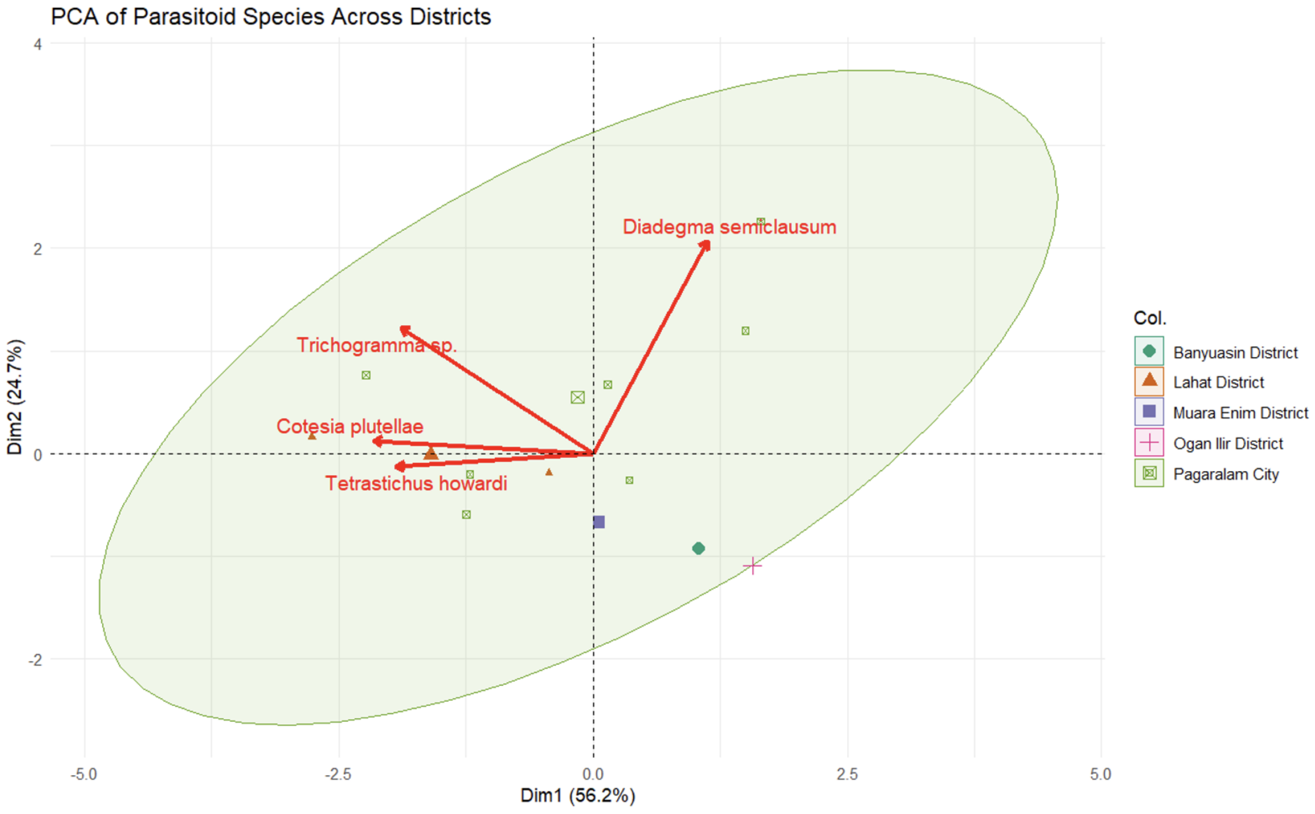

**Figure 8.** Distribution of *Plutella xylostella* parasitoid species in South Sumatra, Indonesia

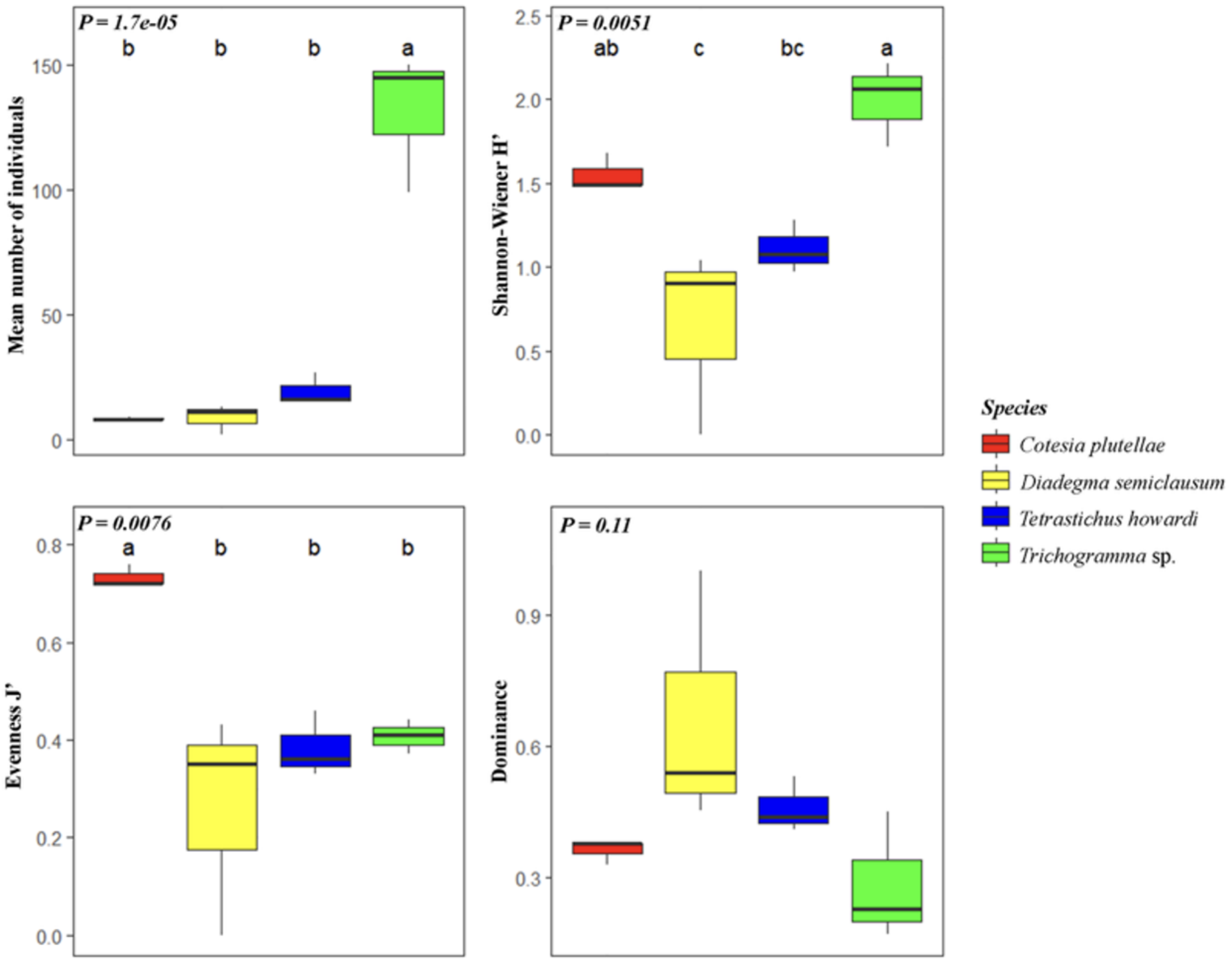

**Figure 9.** Diversity metrics of *Plutella xylostella* parasitoids: mean abundance, Shannon-Wiener H', evenness, and dominance. Different letters denote significant differences among species

## Discussion

*Plutella xylostella* is a major pest of brassica crops. In this study, it was found infesting white mustard, cabbage, and green mustard across both lowland to highland regions of South Sumatra. As a cosmopolitan pest, *P. xylostella* occurs in a wide range of climatic conditions (Li et al. 2016; Bortoli et al. 2020). In South Sumatra, it was particularly abundant in highland areas such as Pagaralam City and Lahat District, where temperatures ranged from 12-24°C. Similarly, in southern Brazil, *P. xylostella* populations peaked during winter, with temperature and rainfall exerting minimal influence on population density (Marchioro and Foerster 2016). In China, the pest is present year-round, with higher population growth during cooler months and lower growth in the summer (Li et al. 2016). Population dynamics and dispersal of *P. xylostella* are strongly influenced by climate, host plant availability, and the abundance of natural enemies (Munir et al. 2015; Li et al. 2016; Marchioro and Foerster 2016). In this study, eggs, larvae, and larval feeding damage were more prevalent in highland regions than in lowlands, likely due to cooler temperatures, higher rainfall, and larger areas of brassica cultivation, which provide favorable conditions for the pest. Larval feeding causes significant crop damage and yield losses, resulting in economic impacts for farmers. Observed symptoms were consistent with previous studies (Paudel et al. 2022), with young larvae creating transparent or "window-like" patches by consuming parenchyma tissue and leaving only the epidermal layer intact (Machekano et al. 2020). Severe infestations can lead to complete defoliation, causing up to 100% yield loss.

The findings of this study revealed four parasitoid species associated with *P. xylostella*: one targeting eggs and three targeting larvae. This represents a decrease in species richness compared to the 2005 survey by Herlinda (2005). Notably, *O. sokolowskii,* previously recorded in Kebun Bunga Village, Palembang City, was absent in the current study. By 2025, the area had been converted into residential land, and no vegetable fields remained. The area of brassica crops influences the number of parasitoid species detected. In 2005, lowland brassica cultivation covered a larger area than in 2025. Much of the lowland vegetable land has since been converted into oil palm plantations and housing, reducing available habitat for parasitoids. In contrast, highland brassica cultivation areas have remained largely stable, with no significant conversion to oil palm plantations observed.

This study identified the egg parasitoid species as *Trichogramma* sp. (Hymenoptera: Trichogrammatidae), while the larval parasitoids were *T. howardi* (Hymenoptera: Eulophidae), *D. semiclausum* (Hymenoptera: Ichneumonidae), and *C. plutellae* (Hymenoptera: Braconidae). *Trichogramma* sp. is a solitary endoparasitoid that targets the eggs of *P. xylostella* (Herlinda 2005; Mason et al. 2022) and was found to be the most abundant and widespread across both lowland and highland of South Sumatra. Similarly, at least one species of egg parasitoid from the family Trichogrammatidae has been reported in Thailand (Paudel et al. 2022). The larval parasitoid *T. howardi* was more abundant in the highlands in this study, although previous research recorded it in lowland areas of South Sumatra (Herlinda 2005; Herlinda et al. 2020a, b). *Tetrastichus howardi* effectively parasitizes *P. xylostella* larvae, and its parasitism rate is not significantly affected by residues of cyantraniliprole or spinetoram (Moraesa et al. 2024). Another larval parasitoid, *D. semiclausum*, is a solitary endoparasitoid that targets *P. xylostella* larvae. In this study, *D. semiclausum* was restricted to high-altitude areas, including Gn. Dempo (1,542 m asl), Dempo Skyline (1,826 m asl), and Jokoh (1,114 m asl) in Pagaralam City, with a maximum parasitism rate of 41.87%. In contrast, *Trichogramma* sp., *T. howardi*, and *C. plutellae* were found throughout both lowland and highland regions of South Sumatra. High-altitude preference for *D. semiclausum* is consistent with studies in Taiwan, where parasitism rates exceed 70% above 1,600 m asl, effectively controlling *P. xylostella* populations (Nam et al. 2022). This species was not detected in lowland areas in the present study, likely due to its adaptation to habitats with temperatures below 25°C. *Diadegma semiclausum* is monophagous, parasitizing only *P. xylostella* larvae (Ayalew and Hopkins 2013). Its introduction has successfully suppressed *P. xylostella* in highland regions such as the Kofele Highlands, where temperatures range from 10-25°C (Ayalew and Hopkins 2013; Sultana et al. 2019).

Higher parasitoid abundance and diversity observed in the highlands may be influenced by greater habitat heterogeneity, vegetation complexity, and floral resource availability that support adult parasitoid foraging and survival. Highland brassica landscapes typically retain more diverse non-crop vegetation, including flowering weeds and nectar-producing plants, which provide essential carbohydrate resources that enhance parasitoid longevity, fecundity, and host-searching efficiency (Gurr et al. 2017). Heterogeneous vegetation also creates microhabitat variation and refugia that buffer parasitoid populations against environmental fluctuations (Tscharntke et al. 2007). These ecological mechanisms likely contribute to the observed gradients in parasitoid diversity between highland and lowland regions.

Although this study did not quantify the relationship between parasitism rates and feeding damage, spatial differences in parasitoid diversity have important implications for ecosystem stability and biological control. More diverse parasitoid assemblages can enhance functional resilience through complementary host ranges, staggered phenologies, and differential responses to microclimatic conditions (Letourneau et al. 2009). The higher parasitoid diversity recorded in highland areas underscores the potential benefits of conserving habitat complexity, such as maintaining flowering weeds, nectar sources, and non-crop vegetation, to support parasitoid populations and strengthen conservation biological control in brassica agroecosystems (Sivinski et al. 2011; Gurr et al. 2017).

In conclusion, the egg and larval parasitoid species of *P. xylostella* recorded in South Sumatra were *Trichogramma* sp., *T. howardi*, *D. semiclausum*, and *C. plutellae*. Among these, *D. semiclausum* was restricted to highland areas, whereas *Trichogramma* sp., *T. howardi*, and *C. plutellae* occurred in both lowlands and highlands. Highland sites exhibited higher egg and larval densities, as well as greater feeding damage, compared to lowland sites. Although parasitoid abundance and species richness were greater in the highlands, this study did not quantitatively assess the relationship between parasitism rates and crop damage, and therefore no conclusions can be drawn regarding the effectiveness of these parasitoids in suppressing *P. xylostella*. Future management efforts could focus on enhancing parasitoid conservation through habitat management, such as maintaining flowering weeds, nectar sources, or pollen refugia, and integrating larval parasitoid conservation with mass releases of egg parasitoids. Also, the identification of parasitoids in this study was based exclusively on morphology. Although this approach is commonly used and was supported by examination from an experienced taxonomist, morphological identification can be challenging for species complexes such as *Trichogramma*. The absence of molecular confirmation (e.g., COI barcoding) represents a limitation of this study. Future studies should integrate molecular markers such as COI barcoding to strengthen parasitoid species identification.

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