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Species diversity and abundance of parasitoids of fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) from South Sumatra, Indonesia

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Abstract. *Herlinda S, Suwandi S, Irsan C, Adrian R, Fawwazi F, Akbar F. 2023. Species diversity and abundance of parasitoids of fall armyworm,* Spodoptera frugiperda *(Lepidoptera: Noctuidae) from South Sumatra, Indonesia. Biodiversitas 24: 6184-6190.* The parasitoid species attacking *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) have never been reported from South Sumatra. The objectives of this research were to identify and analyze the species diversity of egg and larval parasitoids of *S. frugiperda* and to determine their abundance in corn fields from South Sumatra. Surveys were carried out in Ogan Komering Ilir District, Ogan Ilir District, Muara Enim District, and Palembang City. The results showed that fourteen species of parasitoids were found attacking eggs and larvae of *S. frugiperda* in South Sumatra. Two species were egg parasitoids (*Telenomus remus* (Nixon) and *Trichogramma* sp.), and 12 species of larval parasitoids (*Chelonus formosanus* Sonan, *Chelonus oculator* F., *Chelonus annulipes* Wesm., *Chelonus cautus* (Cresson), *Microplitis manilae* Ashmead, *Microplitis marshallii* Kokujev, *Euplectrus corriemoreauae* Hansson, *Compsilura concinnata* (Meigen), *Sarcophaga* sp., *Macrocentrus* sp., *Exorista* sp., and *Megaselia* sp.). The most abundant species of the parasitoids found was *T. remus*. The highest species diversity was found in Muara Enim District. The number of parasitoid species was greater in the dry season compared to the rainy season. Egg parasitism rates were significantly higher at the corn vegetative stage (59.03%) compared to the generative stage (53.56%).

Keywords: Parasitoid species, South Sumatra, species diversity, *Spodoptera frugiperda*

INTRODUCTION

Spodoptera frugiperda J.E. Smith, (1797), Fall Army-Worm (FAW) (Lepidoptera: Noctuidae) is an important insect pest around the world. It is able to invade different habitats and is very voracious, feeding not only on maize but also on other host plant species (Montezano et al. 2018). This pest is native to South America (Otim et al. 2018) which has currently spread to various continents, such as the African Continent (Goergen et al. 2016), Europe (Early et al. 2018), and Asia (Ganiger et al. 2018). The pest arrived in Indonesia in March 2019, and was first discovered in West Sumatra (Sartiami et al. 2020). Currently, *S. frugiperda* has spread throughout Indonesia, including Lampung (Lestari et al. 2020), Bengkulu (Ginting et al. 2020), South Sumatra (Herlinda et al. 2020), Bali (Supartha et al. 2021). The pest is voracious. It attacks more than 353 species from 76 host plant families in Brazil (Montezano et al. 2018). Its damage in Ethiopia and Kenya is 80-100% (Sisay et al. 2019). In Indonesia, the damage can reach 100% in corn plants that are attacked at the beginning of planting (vegetative stage) (Mukkun et al. 2021; Supartha et al. 2021; Herlinda et al. 2022b). In addition, this pest is more dangerous because two strains have been found in Indonesia, namely the rice strain and the corn strain, which have a high potential to damage corn and rice plants (Herlinda et al. 2022b). Financial losses due to pest attacks reach US $ 13 million per year (Harrison et al. 2019).

Spodoptera frugiperda is generally controlled chemically using synthetic insecticides (Kumela et al. 2018; Zhang et al. 2021). The use of synthetic insecticides can kill these pests quickly, but much evidence shows that *S. frugiperda* is resistant to various synthetic insecticides (Zhang et al. 2021). In South Sumatra, FAW attacks reached 100%, even though farmers sprayed insecticides regularly (Herlinda et al. 2022b). Synthetic insecticides can kill parasitoids and predatory arthropods (Seni 2019; Ricupero et al. 2020). Synthetic insecticides can contaminate agricultural products and the environment (Harrison et al. 2019).

Currently, with the increasing demands of green consumers, pest control generally switches to control techniques that are environmentally friendly and healthy, namely biological control, by utilizing natural enemies, such as parasitoids. The dominant egg parasitoid found attacking *S. frugiperda* is *Telenomus remus* (Nixon) (Hymenoptera: Scelionidae) (Kenis et al. 2019), while the parasitoid that attacks the larvae is *Microplitis* sp. (Anandhi and Saminathan 2021). There are six parasitoid species that attack *S. frugiperda* in Bogor District (Tawakkal et al. 2021). *Spodoptera frugiperda* is an invasive pest that arrives in Indonesia without its parasitoids. Therefore, the best strategy to manage this pest is to find indigenous natural enemies in this habitat. Local (indigenous) parasitoids need to be found in other locations in Indonesia, as the more diverse the survey locations, the more diverse the species will be found. There is currently no information on the parasitoid species of *S. frugiperda* eggs and larvae found in South Sumatra. Therefore, research is needed to find parasitoids that attack *S. frugiperda* eggs and larvae in South Sumatra. It is thought that the determination of parasitoid species of *S. frugiperda* will significantly contribute to the biological control of this pest in the region. This study aimed to identify and analyze the species diversity of egg and larval parasitoids of *S. frugiperda* and to determine their abundance.

MATERIALS AND METHODS

Study area

Surveys to obtain specimens of *S. frugiperda* eggs and larvae were carried out in Ogan Komering Ilir District (4°15′S 104.6727°20′E), Ogan Ilir District (3.43186°S 104.6727°E), Muara Enim District (4.2327°S 103.6141°E), and Palembang City (2°59′27.99″S 104°45′24.24″E) (Figure 1). Observations of egg and larval parasitoids of *S. frugiperda* were carried out during two growing seasons, namely rainy (March to May) and dry seasons (June to August) in the Villages of Timbangan (3°12'09"S 104°39'41"E), Lingkar Citra (3°12'39"S 104°39'40"E), Tanjung Pering, (3°13'12"S 104°39'17"E), Tanjung Pering A (3°13'12"S 104°37'47"E), Tanjung Pering B (3°12'45"S 104°38'20"E), Indralaya Sub-district, Ogan Ilir District. The choice of the villages as observation sites was due to the wide expanse of corn (more than 50 ha). The survey began from March to August, covering rainy (March to May) and dry (June to August) seasons. *Spodoptera frugiperda* larvae and eggs obtained were maintained at the Entomology Laboratory of the Department of Plant Protection, Faculty of Agriculture, Universitas Sriwijaya, Indonesia. They were fed corn leaves, and the parasitoids emerging from the larvae or eggs were collected and placed in vials containing 96% ethanol. The adult parasitoids were identified morphologically. Based on certain morphological characters, e.g., venational wing, thorax, antennal flagellum, and abdominal tergite, the adult specimens were identified using methods of Alba (1988), Van Achterberg (1988), Polaszek and Kimani (1990), Zack (1997), Buck et al. (2009), and Hansson et al. (2015). The specimens were examined with an Olympus Zoom Stereo Microscope SZ51 with 30x magnification, and photographs were made with an Optilab Advance Plus Sony IMX577.

Surveys of egg and larval parasitoid of *Spodoptera frugiperda* in South Sumatra

Surveys were carried out to collect egg and larval parasitoids of *S. frugiperda* in vegetative and generative stages of corn in Ogan Komering Ilir District, Ogan Ilir District, Muara Enim District and Palembang City of South Sumatra. From each location, the sample maize field was taken with an area of 1-3 ha per location, and the age of the selected maize ranged from 3 to 6 weeks for the vegetative stage and 6 to 9 weeks for the generative stage following Lestari et al. (2020).

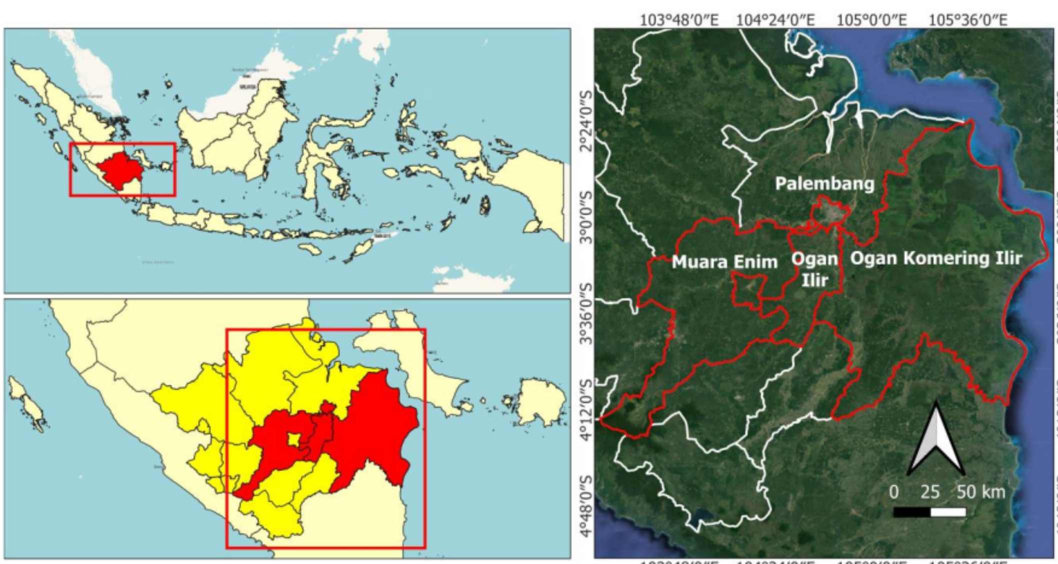

Figure 1. Surveys locations in South Sumatra, Indonesia: Ogan Komering Ilir District, Ogan Ilir District, Muara Enim District and Palembang City, Indonesia

Samplings of parasitoid eggs and larvae of *S. frugiperda* were carried out by using a purposive sampling technique, according to Mukkun et al. (2021). The egg samples collected were 2-3 days old and were characterized by a yellowish-white color and the egg mass was not covered anymore with a felted protective layer of silk. The sample eggs were put into a tst tube (Ø 15 cm, 20 cm high), and every day the parasitoid adults that appeared were observed. The hatches of *S. frugiperda* eggs were also recorded to determine the level of egg parasitization. The morphology of the parasitoid adults was observed to determine the species. The emerging parasitoid adults were put into a vial (5 mL) containing 96% ethanol.

The sample larvae collected were of the third or fourth instar. The sample larvae were obtained from maize fields and then were reared in the laboratory following the method of Herlinda et al. (2022a). The larvae were reared individually in a porous plastic cup (Ø 6.5 cm, height 4.6 cm) because the larvae were cannibals. The larvae were provided with fresh maize leaves every day (2 cm x 5 cm). The number of larval parasitoids and adults of *S. frugiperda* emerging were recorded to determine the parasitization of *S. frugiperda* larvae. The morphology of the parasitoid adults was observed to determine the species. The parasitoid adults that appeared were put into the vial.

Supporting data observed were the percentage of severity or attack intensity and the percentage of plants infested or incidence. The observation of severity and incidence was carried out using a scouting system with protocol following the guidelines of Prasanna et al. (2018). The maize fields were scouted using a "W" pattern approach, and the total sample observed was 30 plants (Prasanna et al. 2018). Larval attack on maize was distinguished by the severity of pinholes, shot holes, lesions, tattering, and dead hearts. The intensity of attack (percentage of severity) was calculated using a rating scale for the severity of damage to whorl-stage plants, and the percentage of maize plants attacked by *S. frugiperda* larvae was termed incidence. The percentage of severity was calculated using a visual severity rating scale from 1 to 5 (Kuate et al. 2019).

Observation of egg and larval parasitoids of *Spodoptera frugiperda* in maize during rainy and dry seasons

Three locations of the maize fields were selected in each village (three replicates) with an area of ± 1 ha each. Sampling of eggs and larvae of *S. frugiperda* was carried out every two weeks, starting from the corn, which was 14 days old up to 70 days old. Maize cultivation techniques follow the habits of local farmers but use synthetic insecticides only when the pest population exceeds the economic threshold. Three locations of maize fields were selected in each village (three replicates) with an area of ± 1 ha each.

Sampling of parasitoid eggs and larvae of *S. frugiperda* was carried out by using a purposive sampling technique. At each location, 30 plants of maize were observed to collect groups of eggs that were 2-3 days old. Every day, the eggs were observed until the parasitoid adults emerged, and all the *S. frugiperda* eggs hatched to determine the parasitization of *S. frugiperda* eggs. The morphology of the parasitoid adults was observed to determine the species. The sample larvae collected were the third or fourth instar, at least 100 larvae per location, and then they were reared in the laboratory following the method of Herlinda et al. (2022a). The number of larval parasitoid adults and *S. frugiperda* adults emerging was recorded to determine the parasitization (parasitism rates) of *S. frugiperda* larvae. The morphology of parasitoid adults was observed to determine the species. The adult parasitoid that appeared was put into the vial.

Data analysis

Egg and larval parasitization (parasitism rates) by parasitoids and incidence and severity of *S. frugiperda* infestation were tested for normality using the Shapiro-Wilk test and for variance homogeneity by Levene's test. Square root transformation was used to homogenize variance and to meet normality assumptions. Tukey's honestly significant test (HSD) was used to compare the differences among the data of each location in a district, and Pearson's Chi-squared was also used to compare parasitization data among districts. R Studio Version 1.4.1106 (R Studio PBC, Boston, MA, USA) was used to calculate the data. The data of parasitoid abundance were also used to analyze the species diversity by using Shannon's Diversity (H'), Pielou's Evenness (E), and Dominance (D) Indexes (Magurran 2004).

RESULTS AND DISCUSSION

Species diversity of egg and larval parasitoids of *Spodoptera frugiferda*

A total of fourteen parasitoid species were found in this study, two species attacking eggs and 12 species attacking larvae of *S. frugiperda*. Of them, only 9 species could be identified at the species level (Figure 2). The egg parasitoids were *T. remus* and *Trichogramma* sp. (Hymenoptera: Trichogrammatidae)., while the larval parasitoids of *S. frugiperda* were *Chelonus formosanus* Sonan (Hymenoptera: Braconidae), *Chelonus oculator* F. (Hymenoptera: Braconidae), *Chelonus annulipes* Wesm. (Hymenoptera: Braconidae), *Chelonus cautus* (Cresson) (Hymenoptera: Braconidae), *Microplitis manilae* Ashmead (Hymenoptera: Braconidae), *Microplitis marshallii* Kokujev (Hymenoptera: Braconidae), *Euplectrus corriemoreauae* Hansson (Hymenoptera: Eulophidae), and *Compsilura concinnata* (Meigen) (Diptera: Tachinidae). Four other larval parasitoid species were found parasitizing the larvae of *S. frugiferda* but could only be identified up to genus level were *Sarcophaga* sp. (Hymenoptera: Sarcophagidae), *Macrocentrus* sp. (Hymenoptera: Braconidae), *Exorista* sp. (Hymenoptera: Tachinidae), and *Megaselia* sp. (Hymenoptera: Phoridae).

Egg parasitism rates of *S. frugiperda* at the corn vegetative stage (59.03%) were significantly higher (p-value = 0.0235) than those at the generative stage (53.56%) (Table 1). However, larval parasitism rates at the corn vegetative (24%) stage were not significantly different (p-value = 0.7463) from those at the generative stage

(23.36%). The incidence of *S. frugiperda* larvae at the corn vegetative (72.36%) was significantly higher (p-value <0.0001) than those at the generative stage (58.60%). The severity of *S. frugiperda* larvae at the corn vegetative (54.05%) was also significantly higher (p-value <0.0001) than those at the generative stage (34.51%).

The highest egg parasitism rate of *S. frugiperda* at corn fields was in Ogan Ilir District (75.68%). This value was significantly different (p-value <0.0001) from other study sites (Table 2). Nevertheless, larval parasitism rates in Ogan Ilir District (17.83%) were not significantly different (p-value = 0.074) from those in Muara Enim District, Palembang City, and Ogan Komering Ilir District. The incidence of *S. frugiperda* larvae in Ogan Komering Ilir District (81%) was the highest among other locations and significantly different (p-value <0.0001). The severity of *S. frugiperda* larvae in Ogan Komering Ilir District (81%) was also the highest among other locations and significantly different (p-value <0.0001).

Table 1. Egg and larval parasitism rates and incidence and severity by *Spodoptera frugiperda* at corn vegetative and generative stage

Corn growing stage	Egg parasitism rates (%)	Larval parasitism rates (%)	Incidence (% of infested plant)	Severity (on a scale of 1 to 5)
Vegetative	59.03^{a} (n = 3056)	24.00 (n = 200)	72.36^{a}	54.05^{a}
Generative	53.56^{b} (n = 506)	26.36 (n = 110)	58.60^{b}	34.51^{b}
χ^2 stat	5.1265*	0.1046^{ns}	21.443**	240.02**
p-value	0.0235	0.7463	3.45×10^{-6}	2.2×10^{-16}

Note: Data labeled by the same letter in the same column are not significantly different from each other (α= 0.05) based on the Pearson's Chi-squared test, n = number of samples (egg or larvae) collected

Table 2. Egg and larval parasitism rates and incidence and severity by *Spodoptera frugiperda* at corn field in South Sumatra

District/city	Egg parasitism rates (%)	Larval parasitism rates (%)	Incidence (% of infested plant)	Severity (on a scale of 1 to 5)
Ogan Ilir	75.68^{c} (n = 1879)	17.83 (n = 129)	63.25^{a}	41.08^{a}
Muara Enim	29.69^{b} (n = 1465)	29.86 (n = 144)	65.40^{a}	44.31^{a}
Palembang	0.00^{a} (n = 0)	18.18 (n = 11)	60.00^{a}	30.74^{b}
Ogan Komering Ilir	100.00^{d} (n = 218)	34.62 (n = 26)	81.00^{b}	68.63^{c}
χ^2 stat	-	6.9327^{ns}	12.207**	94.008**
p-value	2.2×10^{-16}	0.074	0.0067	2.2×10^{-16}

Note: Data labeled by the same letter in the same column are not significantly different from each other (α= 0.05) based on the Pearson's Chi-squared test, n = number of samples (egg or larvae) collected

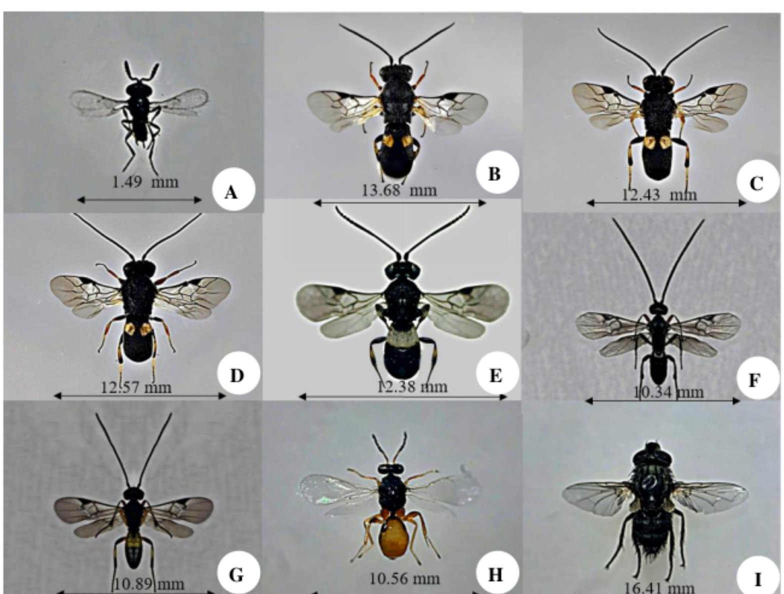

Figure 2. Species of egg and larval parasitoids of *Spodoptera frugiperda*: A. *Telenomus remus* (Nixon), B. *Chelonus formosanus* Sonan, C. *Chelonus annulipes* Wesm., D. *Chelonus oculator* F., E. *Chelonus cautus* (Cresson), F. *Microplitis manilae* Ashmead, G. *Microplitis marshallii* Kokujev, H. *Euplectrus corriemoreauae* Hansson, and I. *Compsilura concinnata* (Meigen)

Abundance of egg and larval parasitoids of *Spodoptera frugiperda*

The most abundant of *S. frugiperda* parasitoid species found in South Sumatra was T. remus (Table 3). The abundance of this species in Ogan Ilir District was the highest and significantly different (p-value <0.0001) from other study sites. Nevertheless, larval abundance in Ogan Ilir District was not significantly different (p-value >0.05) from those in Muara Enim District, Palembang City, and Ogan Komering Ilir District. The highest species diversity was found in Muara Enim District (Table 4). High dominance values occurred at all locations in South Sumatra.

The abundance of egg and larval parasitoids of S. *frugiperda* during a corn growing season in the rainy season (March to May) was lower than those in the dry season (June to August) (Tables 5 and 6). During a corn growing season in the rainy season, the abundance of all parasitoid species in Timbangan Village of Ogan Ilir District was not significantly different (p-value >0.05) from those in other villages. However, during a corn growing season in the dry season, the abundance of egg (*T. remus*) and larval (*M. manilae* and *M. marshalii*) parasitoids in Timbangan Village were significantly different (p-value <0.05) from those in other villages.

Table 3. Abundance of egg and larval parasitoids of *Spodoptera frugiperda* at corn field in South Sumatra

Ordo/family/species	Abundance (individual/30 plants)				
	Ogan Ilir District	Muara Enim District	Palembang City	Ogan Komering Ilir District	p-value
Hymenoptera					
Scelionidae					
Telenomus remus	1422^{a}	435^{b}	0	218^{c}	2.2×10^{-16}
Braconidae					
Chelonus formosanus	7	2	0	0	0.095
Microplitis manilae	0	2	0	0	-
Diptera					
Sarcophagidae				9	-
Sarcophaga sp.	0	0	0		
Tachinidae					
Exorista sp.	2	4	0	0	0.414
Phoridae					
Megaselia sp.	86	204	14	0	0.284
Total	1517	647	14	227	

Note: Data labeled by the same letter in the same column are not significantly different from each other (α= 0.05) based on Pearson's Chi-squared test

Table 4. Species diversity of egg and larval parasitoids of *Spodoptera frugiperda*

Community characteristics	Ogan Ilir District	Muara Enim District	Palembang City	Ogan Komering Ilir District
Abundance	1517	647	14	227
Diversity (H')	0.196	0.698	0.000	0.167
Dominance (D)	0.918	0.552	1.000	0.924
Evennes (E)	0.109	0.390	0.000	0.093

Table 5. The abundance of egg and larval parasitoids of *Spodoptera frugiperda* during a corn growing season in the rainy season (March to May)

Ordo/family/species	Abundance (individual/30 plants)			F-value	p-value	HSD value
	Timbangan	Tanjung Pering A	Tanjung Pering B			
Hymenoptera						
Braconidae						
Microplitis marshalii	0.33	1	1.33	1.96	0.25^{ns}	-
Macrocentrus sp.	0	0.66	0	1.00	0.44^{ns}	-
Chelonus formosus	2.66	0	2.33	1.58	0.31^{ns}	-
Scelionidae	67.66	94.99	73.99	0.18	0.83^{ns}	-
Telenomus remus						
Diptera	1.99	1	0	0.44	0.66^{ns}	-
Sarcophagidae						
Sarcophaga sp.						
Total	72.64	97.65	77.65	5.16	2.49	-

Note: Data labeled by the same letter in the same row are not significantly different from each other (α= 0.05) based on Tukey's honestly significant test

Table 6. Abundance of egg and larval parasitoids of *Spodoptera frugiperda* during a corn growing season in dry season (June to August)

Ordo/family/species	Abundance (individual/30 plants)			F-value	p-value	HSD value
	Timbangan	Tanjung Pering	Lingkar Citra			
Hymenoptera						
Braconidae						
Chelonus formosanus	2.25	0.50	1.00	3.42	0.10[ns]	-
Chelonus oculator	0.75	0.00	0.50	1.62	0.27[ns]	-
Chelonus annulipes	0.25	0.00	0.00	1.00	0.42[ns]	-
Chelonus cautus	0.00	0.00	0.25	1.00	0.42[ns]	-
Microplitis manilae	0.00[a]	0.00 [a]	2.25[b]	24.74	0.0013*	0.26
Microplitis marshallii	0.00[a]	0.00 [a]	1.25[b]	7.51	0.023*	0.29
Eulophidae						
Euplectrus corriemoreauae	0.00	0.50	0.00	1.00	0.42[ns]	-
Scelionidae						
Telenomus remus	119.14[b]	143.35[c]	89.95[a]	14.15	0.005*	4.30
Trichogrammatidae						
Trichogramma sp.	0.00	0.00	1.00	1.00	0.42[ns]	-
Diptera						
Tachinidae						
Comsilura concinatta	0.25	0.00	0.00	1.00	0.42[ns]	-
Total	122.64	144.35	96.20			

Note: Data labeled by the same letter in the same row are not significantly different from each other (α= 0.05) based on Tukey's honestly significant test

Discussion

The first report in Indonesia that there were 14 species of *S. frugiperda* parasitoids found in South Sumatra. Two species were egg parasitoids (*T. remus* and *Trichogramma* sp.), and 12 species of larval parasitoids (*C. formosanus*, *C. oculator*, *C. annulipes*, *C. cautus*, *M. manilae*, *M. marshallii*, *E. corriemorauae*, *C. concinatta*, *Sarcophaga* sp., *Macrocentrus* sp., *Exorista* sp., and *Megaselia* sp.). Some previous studies reported that there were 6 species of parasitoids *S. frugiperda* that have been found in Indonesia, namely *T. remus*, *Trichogramma chilotraeae*, and *M. manilae* (Sari et al. 2023), *Apanteles* sp., *Charops* sp., and *Euplectrus* sp. (Tawakkal et al. 2021). *E. corriemoreauae* found to match the morphology described by Hansson et al. (2015). *Euplectrus corriemoreauae* has never been reported from Indonesia; this parasitoid has only been reported from Costa Rica. Thus, 11 species of larval parasitoids were first recorded in South Sumatra and Indonesia.

In the current study, egg parasitism rates of *S. frugiperda* at the corn vegetative stage were higher than those at the generative stage. The higher egg parasitism rates at the corn vegetative stage were due to a higher egg population of *S. frugiperda* at the vegetative stage. Egg parasitism rates are affected by the host egg population. Because the incidence and severity of *S. frugiperda* larvae were higher at corn vegetative stages, it indicated a higher egg population at the vegetative stage. Nevertheless, larval parasitism rates at the corn vegetative stage were not significantly different from those at the generative stage. *Spodoptera frugiperda* larvae were parasitized by the larval parasitoids starting in the 2nd or 3rd instar. The instars were already solitary because of their cannibalistic nature, so the larval population dilution in the vegetative and generative stages was not as high as the egg population of *S. frugiperda*. The clustering of *S. frugiperda* eggs also affected the abundance of the egg parasitoids. The most abundant egg parasitoid in South Sumatra was *T. remus*. *Telenomus remus* has also spread to various locations in Indonesia, for example, in Bogor (Tawakkal et al. 2021), and it was the most dominant compared to other species in various countries (Sisay et al. 2019; Agboyi et al. 2020). *Spodoptera frugiperda* egg parasitoid, *T. remus* was the most abundant of parasitoid species and has spread to Ogan Ilir District, Muara Enim District, Palembang City, and Ogan Ilir District in South Sumatra. *Telenomus remus* has the potential to be developed as a biological control agent in South Sumatra and in Indonesia. In Africa, *T. remus* is already used in augmentative biological control programs in at least five countries (Kenis et al. 2019). The current study found that *T. remus* was the most abundant among other parasitoid species of *S. frugiperda* that was considered for introduction into other districts in South Sumatra or other provinces in Indonesia. This finding has important implications for the development of augmentative biological control and Integrated Pest Management (IPM) programs against *S. frugiperda,* particularly in South Sumatra and generally in Indonesia.

The highest species diversity was found in Muara Enim District, and the number of larval parasitoid species is greater than the number of egg parasitoid species. Muara Enim has the highest species diversity of the parasitoid because forests and plantations in Muara Enim District are more extensive than in other survey sites. Flora diversity influences arthropod species diversity (Herlinda et al. 2021). In addition, larval parasitoids tended not to dominate in the corn fields, but *T. remus* dominated in all locations in South Sumatra. Species richness of larval parasitoids was high, there were 12 species of larval parasitoids *formosanus* found in the present study, while egg parastoids were only found in two species (*T. remus* and *Trichogramma* sp.). The high species richness of larval parasitoids benefited the stability of the corn ecosystem because the more larval parasitoid species that could control outbreaks of the *S. frugiperda* larvae population, the lower the potential for food webs/chains to break.

The abundance of eggs and larval parasitoids during a corn-growing season in the rainy season (March to May) was lower than those in the dry season (June to August). The abundance of parasitoids was generally influenced by the abundance or population of their host insects (*S. frugiperda*). The population of *S. frugiperda* eggs and larvae was generally lower in the rainy season because pupae in the soil generally fail to become adults due to the higher soil moisture in the rainy season (Caniço et al. 2020). In the current research study, corn field samples for survey locations still used synthetic insecticides, such as chlorantraniliprole, emamectin benzoate, cypermethrin, lambda cyhalothrin, and kresnakum. Local farmers generally sprayed the synthetic insecticide in the vegetative stage. However, the abundance of *T. remus* and *C. formosanus* was still high. The eggs and larval parasitoids persisted and were abundant even when corn plants were sprayed with synthetic insecticide. For this reason, it is necessary to develop strains of egg and larval parasitoids of *S. frugiperda* that are resistant to synthetic insecticides.

In conclusion, there are 14 species of *Spodoptera frugiperda* found in South Sumatra. There are two species of egg parasitoids and 12 species of larval parasitoids. The egg parasitoids are *Telenomus remus* and *Trichogramma* sp. and the larval parasitoids are *Chelonus formosanus*, *Chelonus oculator*, *Chelonus annulipes*, *Chelonus cautus*, *Microplitis manilae*, *Microplitis marshallii*, *Euplectrus corriemoreauae*, *Compsilura concinnata*, *Sarcophaga* sp., *Macrocentrus* sp., *Exorista* sp., and *Megaselia* sp. The most abundant species of the parasitoids found was *T. remus*. The egg parasitoid, *T. remus* was the most abundant and potential parasitoid species to control *S. frugiperda*. The integrated release of egg and larvae parasitoids has the potential to be more effective in controlling *S. frugiperda*. In addition, the high abundance and species diversity of *S. frugiperda* parasitoid species in the maize ecosystem can support integrated pest management in maize fields.

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REFERENCES

Agboyi LK, Goergen G, Beseh P, Mensah SA, Clottey VA, Glikpo R, Buddie A, Cafà G, Offord L, Day R, Rwomushana I, Kenis M. 2020. Parasitoid complex of fall armyworm, *Spodoptera frugiperda*, in Ghana and Benin. Insects 11 (2): 68. DOI: 10.3390/insects11020068.

Alba MC. 1988. Trichogrammatids in the Philippines. Philipp Entomol 7 (3): 253-271.

Anandhi S, Saminathan VR. 2021. New record of larval parasitoids and predatory spiders on fall armyworm *Spodoptera frugiperda* (J.E. Smith) (Noctuidae: Lepidoptera) in Tamil Nadu. J Entomol Zool Stud 9 (4): 340-342.

Buck M, Woodley NE, Borkent A, Wood DM, Pape T, Vockeroth JR, Mchelsen V, Marshall SA. 2009. Key to Diptera families-adults. In: Brown B, Borkent A, Cumming JM, Wood DM, Woodley NE, Zumbado MA (eds). Manual of Central American Diptera. Volume 1, NRC Research Press, Ottawa.

Caniço A, Mexia A, Santos L. 2020. Seasonal dynamics of the alien invasive insect pest *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) in Manica Province, Central Mozambique. Insects 11 (8): 512. DOI: 10.3390/insects11080512.

Early R, González-Moreno P, Murphy ST, Day R. 2018. Forecasting the global extent of invasion of the cereal pest *Spodoptera frugiperda*, the fall armyworm. NeoBiota 40: 25-50. DOI: 10.3897/neobiota.40.28165.

Ganiger PC, Yeshwanth HM, Muralimohan K, Vinay N, Kumar ARV, Chandrashekara K. 2018. Occurrence of the new invasive pest, fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae), in the maize fields of Karnataka, India. Curr Sci 115 (4): 621-623. DOI: 10.18520/cs/v115/i4/621-623.

Ginting S, Zarkani A, Wibowo RH, Sipriyadi. 2020. New invasive pest, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) attacking corn in Bengkulu, Indonesia. Serangga 25 (1): 105-117. https://ejournal.ukm.my/serangga/article/view/37333/10424.

Goergen G, Kumar PL, Sankung SB, Togola A, Tamò M. 2016. First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (J E Smith) (Lepidoptera, Noctuidae), a new alien invasive pest in West and Central Africa. PLoS One 11 (10): e0165632. DOI: 10.1371/journal.pone.0165632.

Hansson C, Smith MA, Janzen DH, Hallwachs W. 2015. Integrative taxonomy of New World Euplectrus Westwood (Hymenoptera, Eulophidae), with focus on 55 new species from Area de Conservación Guanacaste, northwestern Costa Rica. ZooKeys 485: 1-236. DOI: 10.3897/zookeys.485.9124.

Harrison RD, Thierfelder C, Baudron F, Chinwada P, Midega C, Schaffner U, van den Berg J. 2019. Agro-ecological options for fall armyworm (*Spodoptera frugiperda* JE Smith) management: Providing low-cost, smallholder friendly solutions to an invasive pest. J Environ Manag 243: 318-330. DOI: 10.1016/j.jenvman.2019.05.011.

Herlinda S, Gustianingtyas M, Suwandi S, Suharjo R, Sari JMP, Suparman, Hamidson H, Hasyim H. 2022a. Endophytic fungi from South Sumatra (Indonesia) in seed-treated corn suppressing *Spodoptera frugiperda* growth. Biodiversitas 23 (11): 6013-6020. DOI: 10.13057/biodiv/d231156.

Herlinda S, Octariati N, Suwandi S, Hasbi. 2020. Exploring entomopathogenic fungi from South Sumatra (Indonesia) soil and their pathogenicity against a new invasive maize pest, *Spodoptera frugiperda*. Biodiversitas 21 (7): 2955-2965. DOI: 10.13057/biodiv/d210711.

Herlinda S, Suharjo R, Sinaga ME, Fawwazi F, Suwandi S. 2022b. First report of occurrence of corn and rice strains of fall armyworm, *Spodoptera frugiperda* in South Sumatra, Indonesia and its damage in maize. J Saudi Soc Agric Sci 21 (10): 412-419. DOI: 10.1016/j.jssas.2021.11.003.

Herlinda S, Tricahyati T, Irsan C, Karenina T, Hasbi, Suparman, Lakitan B, Anggraini E, Arsi. 2021. Arboreal arthropod assemblages in chili pepper with different mulches and pest management in freshwater swamps of South Sumatra, Indonesia. Biodiversitas 22 (6): 3065-3074. DOI: 10.13057/biodiv/d220608.

Kenis M, du Plessis H, Van den Berg J, Ba MN, Goergen G, Kwadjo KE, Baoua I, Tefera T, Buddie A, Cafà G, Offord L, Rwomushana I, Polaszek A. 2019. *Telenomus remus*, a candidate parasitoid for the biological control of *Spodoptera frugiperda* in Africa, is already present on the continent. Insects 10 (4): 92. DOI: 10.3390/insects10040092.

Kuate AF, Hanna R, Fotio ARPD, Abang AF, Nanga SN, Ngatat S, Tindo M, Masso C, Ndemah R, Suh C, Fiaboe KKM. 2019. Correction: *Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae) in Cameroon: Case study on its distribution, damage, pesticide use, genetic differentiation and host plants. PLoS One 14 (6): e0217653. DOI: 10.1371/journal.pone.0217653.

Kumela T, Simiyu J, Sisay B, Likhayo P, Mendesil E, Gohole L, Tefera T. 2018. Farmers knowledge, perceptions, and management practices of the new invasive pest, fall armyworm (*Spodoptera frugiperda*) in Ethiopia and Kenya. Intl J Pest Manag 65 (1): 1-9. DOI: 10.1080/09670874.2017.1423129.

Lestari P, Budiarti A, Fitriana Y, Susilo F, Swibawa IG, Sudarsono H, Suharjo R, Hariri AM, Purnomo, Nuryasin, Solikhin, Wibowo L, Jumari, Hartaman M. 2020. Identification and genetic diversity of *Spodoptera frugiperda* in Lampung Province, Indonesia. Biodiversitas 21 (4): 1670-1677. DOI: 10.13057/biodiv/d210448.

Magurran AE. 2004. Measuring Biological Diversity. Blackwell Science Ltd., USA

Montezano DG, Specht A, Sosa-Gómez DR, Roque-Specht VF, Sousa-Silva JC, Paula-Moraes SV, Peterson JA, Hunt TE. 2018. Host plants of *Spodoptera frugiperda* (Lepidoptera : Noctuidae) in the Americas. Afr Entomol 26 (2): 286-300. DOI: 10.4001/003.026.0286.

Mukkun L, Kleden YL, Simamora AV. 2021. Detection of *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) in maize field in East Flores District, East Nusa Tenggara Province, Indonesia. Intl J Trop Drylands 5 (1): 20-26. DOI: 10.13057/tropdrylands/t050104.

Otim MH, Tay WT, Walsh TK, Kanyesigye D, Adumo S, Abongosi J, Ochen S, Sserumaga J, Alibu S, Abalo G, Asea G, Agona A. 2018. Detection of sister-species in invasive populations of the fall armyworm *Spodoptera frugiperda* (Lepidoptera : Noctuidae) from Uganda. PLoS One 13 (4): e0194571. DOI: 10.1371/journal.pone.0194571.

Polaszek A, Kimani SW. 1990. *Telenomus species* (Hymenoptera: Scelionidae) attacking eggs of pyralid pests (Lepidoptera) in Africa: A review and guide to identification. Bull Entomol Res 80 (1): 57-71. DOI: 10.1017/S0007485300045922.

Prasanna BM, Huesing JE, Eddy R, Peschke VM. 2018. Monitoring, surveillance, and scouting for fall armyworm. In: Prasanna BM, Huesing JE, Eddy R, Peschke VM (eds). Fall Armyworm Africa: A Guide for Integrated Pest Management. USAID and CIMMYT, Mexico.

Ricupero M, Desneux N, Zappalà L, Biondi A. 2020. Target and non-target impact of systemic insecticides on a polyphagous aphid pest and its parasitoid. Chemosphere 247: 125728. DOI: 10.1016/j.chemosphere.2019.125728.

Sari A, Nurkomar I, Buchori D. 2023. Comparison of *Spodoptera frugiperda* parasitoid performance under laboratory conditions. IOP Conf Ser: Earth Environ Sci 1220: 012031. DOI: 10.1088/1755-1315/1220/1/012031.

Sartiami D, Dadang, Harahap IS, Kusumah YM, Anwar R. 2020. First record of fall armyworm (*Spodoptera frugiperda*) in Indonesia and its occurence in three provinces. IOP Conf Ser: Earth Environ Sci 468: 012021. DOI: 10.1088/1755-1315/468/1/012021.

Seni A. 2019. Impact of certain essential oils and insecticides against major insect pests and natural enemies in rice. J Cereal Res 11 (3): 252-256. DOI: 10.25174/2249-4065/2019/95533.

Sisay B, Simiyu J, Mendesil E, Likhayo P, Ayalew G, Mohamed S, Subramanian S, Tefera T. 2019. Fall armyworm, *Spodoptera frugiperda* infestations in East Africa: Assessment of damage and parasitism. Insects 10 (7): 195. DOI: 10.3390/insects10070195.

Supartha IW, Susila IW, Sunari AAAAS, Mahaputra IGF, Yudha IKW, Wiradana PA. 2021. Damage characteristics and distribution patterns of invasive pest, *Spodoptera frugiperda* (J.E Smith) (Lepidoptera: Noctuidae) on maize crop in Bali, Indonesia. Biodiversitas 22 (6): 3378-3387. DOI: 10.13057/biodiv/d220645.

Tawakkal MI, Buchori D, Maryana N, Pudjianto. 2021. New association between *Spodoptera frugiperda* J.E. Smith (Lepidoptera: Noctuidae) and native natural enemies: Bioprospection of native natural enemies as biological control agents. IOP Conf Ser: Earth Environ Sci 771: 012030. DOI: 10.1088/1755-1315/771/1/012030.

Van Achterberg C. 1988. Revision of the subfamily Blacinae Foerster (Hymenoptera: Braconidae). Zool Verh 249 (1): 1-324.

Zack RS. 1997. Manual of the new world genera of the family Braconidae (Hymenoptera). Ann Entomol Soc Am 92 (4): 615-616. DOI: 10.1093/aesa/92.4.615.

Zhang D-D, Xiao Y-T, Xu P-J, Yang X-M, Wu Q-L, Wu K-M. 2021. Insecticide resistance monitoring for the invasive populations of fall armyworm, *Spodoptera frugiperda* in China. J Integr Agric 20 (3): 783-791. DOI: 10.1016/S2095-3119(20)63392-5.

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