

Invasion of fall armyworm *Spodoptera frugiperda*, a new invasive pest, alters native herbivore attack intensity and natural enemy diversity

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Abstract. Rizali A, Oktaviyani, Putri SDPS, Doananda M, Linggani A. 2021. Invasion of fall armyworm *Spodoptera frugiperda*, a new invasive pest, alters native herbivore attack intensity and natural enemy diversity. *Biodiversitas* 22: 3482-3488. A new invasive alien pest, fall armyworm *Spodoptera frugiperda* has been reported widely spread in Indonesia since 2019 and can cause a serious problem in maize cultivation. Its invasion of new habitat may severely impact not only maize production but also native biodiversity including other native pests. This research was aimed to investigate the effect of *S. frugiperda* invasion on the attack intensity of native herbivores as well as the diversity of natural enemies in maize fields. Field research was conducted in twelve maize fields spread across the district of Malang, Kediri, and Batu, East Java, Indonesia. In each maize field, sampling of *S. frugiperda* and other insects was conducted by the hand-picking method within four transects with each transect consisting of 100 plants. The results found five species of lepidopteran pests including *S. frugiperda*, *Ostrinia furnacalis*, *Helicoverpa armigera*, *Mycalesis* sp, and *Chrysodeixes* sp. *S. frugiperda* was found with higher attack intensity than other lepidopteran pests. Based on the analysis, the attack intensity of *S. frugiperda* had a positive relationship with pesticide application and was marginally correlated with plant age and elevation. The infestation of *S. frugiperda* significantly reduced the attack intensity of other lepidopteran pests as well as the diversity of natural enemies, especially predators. Two native species of parasitoid wasps, *Telenomus* sp and *Mymaridae* sp were recorded parasitizing the eggs of *S. frugiperda*. In conclusion, the infestation of *S. frugiperda* causes biotic homogenization in the maize field by directly compete with other lepidopteran pests and indirectly eliminate the natural enemy diversity.

Keywords. Invasive species, lepidopteran pest, maize field, parasitoid, predator

INTRODUCTION

The invasion of invasive alien insects in new regions or habitats can cause a negative effect on native biodiversity (McGeoch et al. 2015; Hill et al. 2016). Several well-known mechanisms by which alien insects impact native biodiversity are competition (Rowles and O'Dowd 2007), predation (Roy and Brown 2015), disease transmission (Jacobi et al. 2013), and herbivory (Herms and McCullough 2014). A review by McGeoch et al. (2015) presented that herbivory is the most frequent mechanism and among other insect orders, Coleoptera and Hemiptera are the main orders that contributing to this impact mechanism. For instance, *Agrilus planipennis* or emerald ash borer (Coleoptera: Buprestidae) can cause millions of ash trees to be killed in North America and also cause changes to understorey environment as well as a reduction in food sources for other arthropod herbivores (Herms and McCullough 2014). In addition, the invasion of invasive insects besides negatively affects the environment, also significantly affects socio-economy such as damage to forestry, agriculture, as well as human health (McGeoch et al. 2015). Therefore, more efforts are needed to mitigate and adapt to the effects of invasive insects due to can affect food security in a country (Cook et al. 2011).

Although Indonesia, as one of the countries in the world with the level of invasion threat by insects is relatively low

(Paini et al. 2016), the invasion of invasive insects can severely affect native biodiversity, environment, and socio-economy. However, as a tropical country and with high biodiversity and endemism (Myers et al. 2000), Indonesia is vulnerable to the invasion of invasive pests (Paini et al. 2016). In 2019, Indonesia was invaded by a new invasive alien pest, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae). *S. frugiperda* or fall armyworm was firstly recorded in West Sumatera (Trisyono et al. 2019; Sartiami et al. 2020) and then spread to other islands including Java Island in the same year (Maharani et al. 2019; Asfiya et al. 2020). *S. frugiperda* is native to America and since 2016, it has been aggressively moving over eastwards, spread widely across Africa, and introduce for the first time in Asia in mid-2018 in India. In January of 2019, *S. frugiperda* has spread to China, Myanmar, and Thailand before arriving in Indonesia. As a polyphagous insect, *S. frugiperda* can cause serious damage to the maize plant and cause high economic losses. While economic losses in Indonesia have not yet been estimated, the infestation of *S. frugiperda* has the potential to cause maize yield losses of 8.3 to 20.6 million tonnes annually with valued at between US\$2.5 to US\$6.2 billion without control efforts (FAO & CABI 2019).

Besides the effect on economic loss, the invasion of *S. frugiperda* may also affect native biodiversity. In Africa, the infestation of *S. frugiperda* can affect the native

biodiversity by reducing both native insect pests and other insect communities (Sokame et al. 2021b; Sokame et al. 2021a). Larvae of *S. frugiperda* have the ability to compete (intraspecific competition) and predate other larvae (cannibalism) (Chapman et al. 2000; Ren et al. 2020). *S. frugiperda* larvae can also reduce the larvae of other lepidopteran pests through interference competition and predation (Wiseman and McMillian 1969; Song et al. 2021). In addition, the infestation of *S. frugiperda* was also reported to have a negative effect on natural enemies especially parasitoids by decrease the parasitism rate on native stem borers (Sokame et al. 2021b). However, as a consequence of the presence of new species in a habitat, *S. frugiperda* can interact with native species both of predators and parasitoids. It has been documented in Africa that *S. frugiperda* can be parasitized by a native parasitoid wasp, *Cotesia icipe* (Hymenoptera: Braconidae) which is the dominant parasitoid of *S. frugiperda* larvae in Kenya, Ethiopia, and Tanzania (Sisay et al. 2018).

The objective of this research was to investigate the effect of the invasion of *S. frugiperda* on the attack intensity of native lepidopteran pests and the diversity of natural enemies. The research was conducted on several maize (*Zea mays*) fields in East Java. It has been documented that maize in Indonesia has main lepidopteran pests such as Asian corn borer, *Ostrinia furnacalis* (Guenée) (Lepidoptera: Crambidae), and corn earworm *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) (Kalshoven 1981). The invasion of *S. frugiperda* may have a negative impact on the attack intensity of other lepidopteran pests due to its feeding behavior overlap with other lepidopteran pests such as feed on foliage, stem, and also ears of the maize plant. Thus, this research hypothesizes that the invasion of *S. frugiperda* will reduce the attack intensity of other lepidopteran pests and also reduce the diversity of natural enemies in maize fields.

MATERIALS AND METHODS

Research location and transect selection

The research was conducted in twelve maize fields located in different villages spread across three districts i.e., Malang, Batu, and Kediri within the province of East Java (Figure 1). Maize fields were chosen by considering the minimum area is 800 m², minimum plant age is 3 weeks after planting, and minimum distance from other maize fields is 2 km. In each maize field, four transects were determined as a sampling unit with each transect consisting of 100 maize plants. In addition, interviews with the owner of the maize field were also conducted to provide information about cultivation techniques including the size of a maize field, maize variety, plant age, and intensity of pesticide application (Table 1).

Sampling of lepidopteran pests and natural enemies

The lepidopteran pests and natural enemies were sampled from January to March 2020 using a hand-picking method. The damaged symptoms due to lepidopteran larvae were also observed that can be distinguished especially between *S. frugiperda* and other lepidopteran pests. For instance, the damages of *S. frugiperda* on maize leaves is indicated by the presence of feces and the window-like symptom on the whorl with the size of holes are greater than *O. furnacalis* (Trisyono et al. 2019). In each maize field, sampling and observation were carried out three times in the vegetative phase (3 and 5 weeks old) and generative phase (7 weeks old). Lepidopteran pests and natural enemies were sampled and observed on each maize plant for a maximum of 30 minutes per transect. The attack symptoms were also noted to get the data of attack intensity of each lepidopteran pest. In this research, non-pests of lepidopteran were not found during the observation in all maize fields. Eggs and larvae of lepidopteran pests were collected and placed individually into a plastic container and were brought to the laboratory. Eggs and larvae were observed daily to record the parasitoid or adult emergence.

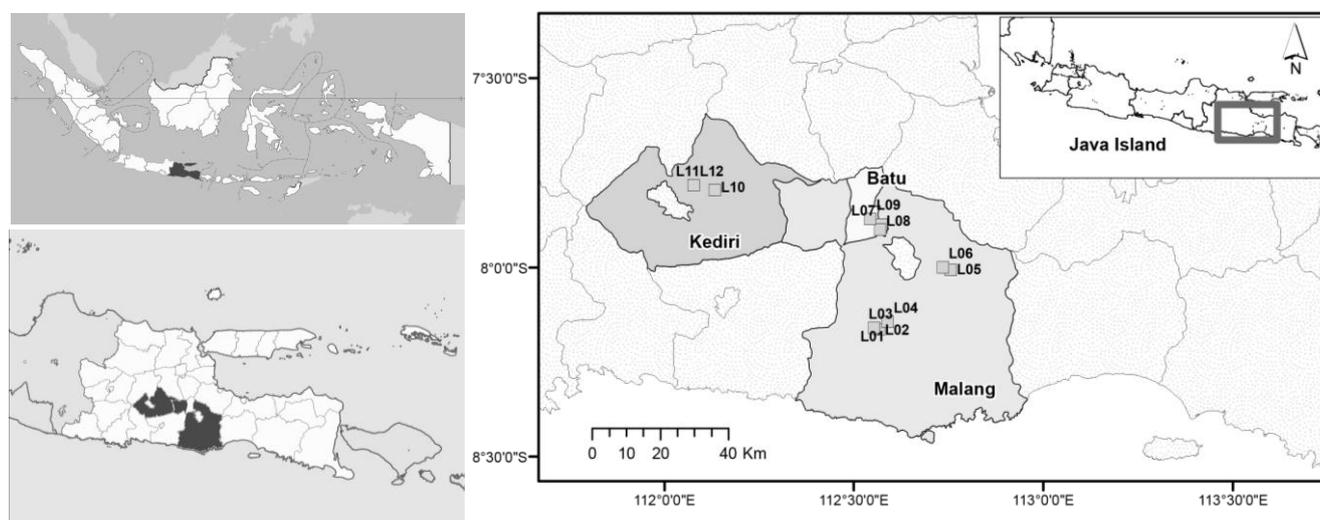


Figure 1. Map of research location in twelve maize fields in East Java, Indonesia. The letter and number refer to the plot code listed in Table 1

Table 1. Characteristic of research location located in twelve different maize fields in East Java, Indonesia

Plot code	District	Village	Elevation (m asl*)	Variety	Field size (m ²)	Pesticide application**
L01	Malang	Sukorejo	358	Lokal super	2,500	1
L02	Malang	Kemiri	337	Mentari	2,500	2
L03	Malang	Pasangrahan	340	Lokal super	5,000	0
L04	Malang	Poncokusumo	563	Talenta	1,500	4
L05	Malang	Tumpang	595	Talenta	2,500	15
L06	Malang	Bokor	552	Pioner	5,500	1
L07	Batu	Tawang Argo	710	Pertiwi	2,000	10
L08	Batu	Krajan	658	Talenta	2,000	20
L09	Batu	Pandanrejo	852	Talenta	800	10
L10	Kediri	Tiru Lor	131	BISI-99	3,500	0
L11	Kediri	Menang	143	Perkasa	1,050	4
L12	Kediri	Kawedusan	103	Talenta	2,800	18

Note: * asl: above sea level; **: number of pesticide applications per planting season

Whilst, the specimens of natural enemies were preserved in the plastic vials with 70% alcohol for later identification in the laboratory. All specimens were identified to morphospecies level based on their morphological characteristics using available references e.g. Borror et al. (1996), Bolton (1994), and Goulet and Huber (1993).

Data Analysis

To calculate the attack intensity (%) of each lepidopteran pest was based on the number of attacked plants divided by the total number of observed plants x 100%. Multiple regression analysis was used to analyze the relationship between attack intensity of lepidopteran pests and maize field characteristics i.e., elevation, plant age, and pesticide application. In addition, regression analysis was used to analyze the relationship between the invasion of *S. frugiperda* and other lepidopteran pests as well as natural enemies. All analyses were performed using R statistical software (R Core Team 2020).

RESULTS AND DISCUSSION

Diversity and attack intensity of lepidopteran pests in maize fields

The research recorded five species of lepidopteran pests attacking maize plants from twelve locations i.e., *S. frugiperda* (Family Noctuidae), *O. furnacalis* (Family Crambidae), *H. armigera* (Family Noctuidae), *Mycalesis* sp or green-horned caterpillar (Family Nymphalidae), and *Chrysodeixes* sp or corn semi-looper (Family Noctuidae). *S. frugiperda* was almost found in all maize fields except in Pasangrahan village and a higher attack intensity (average 4%-26.3%) than other lepidopteran pests (Table 2). Similar to *S. frugiperda*, *H. armigera* was also almost found in all locations except Kemiri village (Table 2). According to sampling time or plant age, *H. armigera*, as well as *O. furnacalis*, did not find in 3 weeks after planting (WAP), while *S. frugiperda* was found in all sampling times (Figure 2). The lowest occurrence and attack intensity of

lepidopteran pests are by *Chrysodeixes* sp that only found in two locations with average attack intensity between 0.1%-1.5%, and did not record in plant age of 7 WAP.

As the main lepidopteran pests of maize, *O. furnacalis* and *H. armigera* were commonly recorded in maize fields in Indonesia. *O. furnacalis* feed on the foliage, but then move into the stems while *H. armigera* feed on both silk and within the ears (Capinera 2008; Maharani et al. 2019). In this research, *S. frugiperda* was also recorded as a new invasive species to invade maize fields in East Java. After being firstly reported in 2019 (Trisyono et al. 2019), *S. frugiperda* was intensively surveyed and in the same year have been detected in West Java (Maharani et al. 2019; Asfiya et al. 2020). In early 2020, when this research was conducted, *S. frugiperda* has been infested the maize fields in Kediri, Malang, and Batu, East Java, although certain maize fields are still not invaded by this pest. As a new pest, the attack intensity of *S. frugiperda* was found higher than other lepidopteran pests. However, the attack intensity in East Java was lower than in West Java that can reach 78% to 100% (Asfiya et al. 2020).

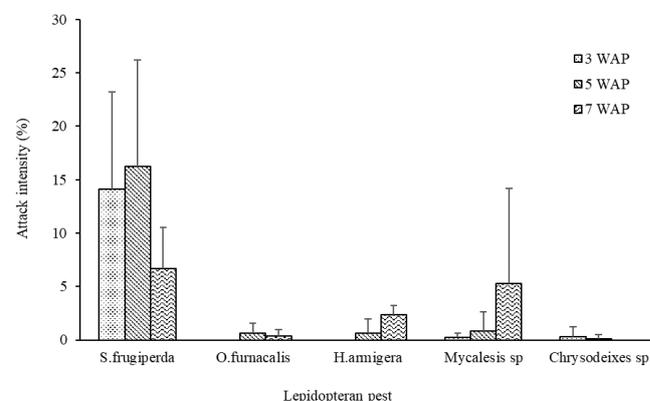


Figure 2. Difference of lepidopteran pest attack intensity (mean ± SD) between plant age of maize. WAP: weeks after planting

Table 2. Attack intensity (means \pm SD) of lepidopteran pests from different maize fields

Code	Village	<i>S. frugiperda</i>	<i>O. furnacalis</i>	<i>H. armigera</i>	<i>Mycalesis sp</i>	<i>Chrysodeixes sp</i>
L01	Sukorejo	4.0 \pm 1.8	0.9 \pm 0.9	1.8 \pm 1.8	7.8 \pm 11.4	0
L02	Kemiri	4.7 \pm 1.4	0.5 \pm 0.9	0	8.3 \pm 13.0	0
L03	Pasangrahan	0	0	1.1 \pm 1.9	7.1 \pm 6.5	0
L04	Poncokusumo	10.3 \pm 3.8	0.5 \pm 0.9	1.8 \pm 1.8	0	0
L05	Tumpang	17.8 \pm 7.0	1.0 \pm 1.0	0.8 \pm 1.4	0	0
L06	Bokor	9.1 \pm 4.4	1.2 \pm 1.1	0.9 \pm 1.6	0	0
L07	Tawang Argo	20.2 \pm 8.2	0	1.0 \pm 1.3	0	0.1 \pm 0.1
L08	Krajan	26.3 \pm 12.2	0	0.8 \pm 1.4	0	0
L09	Pandanrejo	17.7 \pm 7.0	0	0.9 \pm 1.6	0	0
L10	Tiru Lor	16.9 \pm 6.6	0	0.8 \pm 1.4	0	0
L11	Menang	9.8 \pm 4.2	0	0.8 \pm 1.4	0.4 \pm 0.5	0
L12	Kawedusan	11.6 \pm 4.3	0	1.1 \pm 1.9	1.7 \pm 2.9	1.5 \pm 1.6

The potential of damage level by arthropod pests in maize is about 14–17% worldwide (Capinera 2008), thus with such a level of damage, *S. frugiperda* becomes the most destructive pest than other lepidopteran pests. The damage due to *S. frugiperda* does not always cause plant mortality but always causes significant yield reduction (28% per plant) especially when the plants were infested during the first to second week after germination (Evans and Stansly 1990). Research by Niassy et al. (2021) also found that the infestation of *S. frugiperda* was varied between crop phenology with infestation being high at the vegetative stages of the maize. With the actual level of attack intensity of *S. frugiperda*, it is needed a comprehensive approach to mitigating the damaging effect of the infestation of this pest in maize fields.

The results of multiple linear regression showed that the attack intensity of *S. frugiperda* had a positive relationship with the intensity of pesticide application ($P=0.001$; Table 3). Increasing the intensity of pesticide application in maize fields tends to increase the attack intensity of *S. frugiperda*. It is possibly due to the invaded species has already been resistant to insecticide since from the origin area that had been reported e.g. by Yu (1992) and Carvalho et al. (2013). In contrast, *O. furnacalis* ($P=0.256$) and *H. armigera* ($P=0.879$) were not related to pesticide application (Table

3). Although pesticide application can cause resistance to those pests, the resistance may in the lower level than *S. frugiperda*. A study by Torres-Vila et al. (2002) revealed that insecticide resistance in *H. armigera* occurs but lower depend on the geographical regions. In relation to the elevation factor, the attack intensity of *S. frugiperda*, *H. armigera*, and *O. furnacalis* was not correlated with the elevation of a maize field. Elevation which is also related to temperature tends to have an effect on the life-history of lepidopteran pests than the attack intensity that had been shown for *O. furnacalis* (Xiao et al. 2016). In addition, plant age had a positive relationship with the attack intensity of *H. armigera* ($P<0.001$) but not with *O. furnacalis* ($P=0.120$). As the corn earworm, *H. armigera* prefers feeding on the ear (Capinera 2008), thus the attack intensity was occurred in 5 WAP and increase in 7 WAP (Figure 2). In other crops such as tomato (*Solanum lycopersicum*), the infestation of *H. armigera* also revealed had a relationship with plant phenology (Torres-Vila et al. 2003). The attack intensity of *S. frugiperda* was also tended to relate with plant age, although with marginal significance ($P=0.053$). Based on Trisyono et al. (2019), the damage by *S. frugiperda* was related to the plant age and the larvae prefer to infest the young maize.

Table 3. Multiple regression relating attack intensity of lepidopteran pests to plant age, elevation, and pesticide application as predictors. Significance level **: $P<0.01$

Variable	<i>S. frugiperda</i>		<i>O. furnacalis</i>		<i>H. armigera</i>		<i>Mycalesis sp</i>		<i>Chrysodeixes sp</i>	
	Estimate	P	Estimate	P	Estimate	P	Estimate	P	Estimate	P
(Intercept)	10.573	0.017	-0.256	0.533	-2.024	0.001	-0.277	0.933	0.753	0.015
Age	-0.133	0.053	0.010	0.120	0.059	<0.001**	0.097	0.068	-0.008	0.089
Elevation	0.010	0.067	0.000	0.393	0.000	0.885	-0.003	0.394	-0.001	0.005**
Pesticide	0.632	0.001**	-0.019	0.256	-0.004	0.879	-0.171	0.207	0.039	0.002**

Effect of *S. frugiperda* invasion on attack intensity of native lepidopteran pests and diversity of natural enemies

Based on regression analysis, the attack intensity of *S. frugiperda* had a negative effect on the attack intensity of *H. armigera* ($P=0.016$) and *Mycalesis* sp ($P=0.009$) but did not have an effect on *O. furnacalis* ($P=0.519$) and *Chrysodeixes* sp ($P=0.775$) (Table 4).

Research by Sokame et al. (2021b) also revealed that the introduction of the *S. frugiperda* in maize fields was strongly related to the decrease of the abundance of stem borers in Kenya. In this research, *S. frugiperda* and *O. furnacalis* did not find co-exist in the same maize plant, even with *H. armigera*. This is perhaps due to the overlap of feeding behavior between *S. frugiperda* and other lepidopteran pests. According to Trisyono et al. (2019), *O. furnacalis* has the same feeding behavior as *S. frugiperda* that was initially fed on the foliage and then move into the stems. With this behavior, *S. frugiperda* can potentially replace the presence of *O. furnacalis*. As invasive species, besides the ability on intraspecific competition (Morrill and Greene 1973; Labatte 1993), larvae of *S. frugiperda* has also ability to reduce and replace other lepidopteran larvae by interference competition and predation (Wiseman and McMillian 1969; Song et al. 2021). The competition and displacement could be occurred due to *S. frugiperda* and stem borer share the same maize resource, as previously demonstrated among lepidopteran stem borers in laboratory and greenhouse (Ntiri et al. 2016; Ntiri et al. 2017) as well as in field experiments (Ntiri et al. 2019).

This research also observed the diversity of natural enemies both predators and parasitoids that are associated with *S. frugiperda* as well as other lepidopteran pests. In total, 17 species of predators and two species of parasitoid wasps were recorded from all locations (Table 5). Predators are grouped into three taxa i.e., ants, beetles, and spiders, while parasitoid wasps were recorded only from the eggs and were not found from the larvae of *S. frugiperda*. Two species of egg parasitoids, *Telenomus* sp., and Mymaridae sp. are native parasitoids that can parasitize the eggs of *S. frugiperda* (Figure 3). Based on the regression analysis, the invasion of *S. frugiperda* had a negative effect on the diversity of predators ($P=0.031$; Table 4). Parasitoids were excluded in the analysis due to only being found in three locations. Although the mechanism is not clear yet, the decrease of predator diversity was perhaps related to the decrease of native pests as a consequence of the invasion of

S. frugiperda. It has been shown for parasitoids that the invasion of *S. frugiperda* was reported to have a negative effect on parasitoids especially decrease the parasitism rate of stem borers (Sokame et al. 2021b). This is due to the abundance of parasitoids that may follow the abundance of pests (Sokame et al. 2021a). This pattern accepts the hypothesis that interaction diversity is linked to the Lotka-Volterra prey-predator system, which is the positive correlation between pest abundance and natural enemies (Boukal and Krivan 1999).

This research was conducted around a year after the invasion of *S. frugiperda* in Indonesia and it recorded a new association between two species of native parasitoids and *S. frugiperda* in East Java. Although this research was not recorded yet, there will be a possibility of the association of native parasitoids that parasitize the larvae of *S. frugiperda*. In Africa, a native parasitoid, *Cotesia icipe* (Hymenoptera: Braconidae) has been recorded to be the dominant parasitoid of *S. frugiperda* larvae in Kenya, Ethiopia, and Tanzania (Sisay et al. 2018). Even, other local parasitoids such as *Cotesia flavipes* and *Cotesia sesamiae* can parasitize the larvae of *S. frugiperda* under laboratory conditions, although failed to develop (Sokame et al. 2020). As a consequence of these interferences, it has an effect on a pre-existing biological control process of *S. frugiperda* (Desurmont et al. 2014; Chabaane et al. 2015). This condition might be an advantage for *S. frugiperda* exhibit significant outbreaks due to lower demographic pressure from natural enemies (Abram et al. 2014).

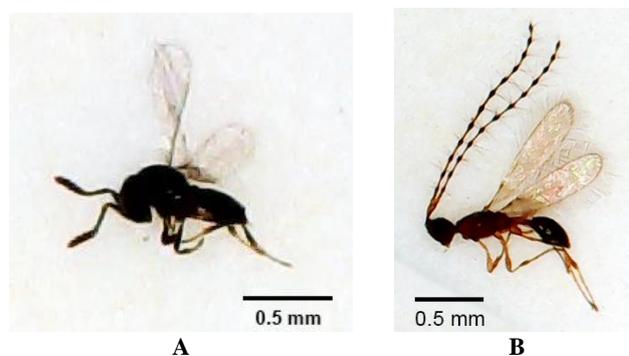


Figure 3. Parasitoid wasps were found emerging from the eggs of *S. frugiperda*. A. *Telenomus* sp., B. Mymaridae sp.

Table 4. Relationship between attack intensity of native lepidopteran pests and species richness of predators and *S. frugiperda* attack intensity. Significance level *: $P<0.05$, **: $P<0.01$

Variable	<i>O. furnacalis</i>		<i>H. armigera</i>		<i>Mycalesis</i> sp		<i>Chrysodeixes</i> sp		Predator	
	Estimate	P	Estimate	P	Estimate	P	Estimate	P	Estimate	P
(Intercept)	0.444	0.030	1.752	0.000	5.410	0.001	0.093	0.584	5.611	0.000
<i>S. frugiperda</i>	-0.008	0.519	-0.061	0.016*	-0.268	0.009**	0.003	0.775	-0.074	0.031*

Table 5. Morphospecies and individual number of predators and parasitoids from different maize fields. The letter and number of maize fields refer to the plot code listed in Table 1

Morphospecies	Maize fields											
	L01	L02	L03	L04	L05	L06	L07	L08	L09	L10	L11	L12
Predator-Ants												
<i>Anoplolepis gracilipes</i>	57	12	0	0	4	0	0	0	61	12	0	0
<i>Dolichoderus</i> sp	0	0	0	0	0	37	32	8	3	113	0	38
<i>Pheidole</i> sp1	0	21	26	0	0	0	0	0	34	5	0	12
<i>Pheidole</i> sp2	0	2	2	0	0	0	0	0	0	0	0	0
<i>Polyrhachis</i> sp	0	0	0	4	0	0	0	0	0	0	153	0
<i>Tapinoma</i> sp	0	0	0	0	0	0	0	5	20	0	0	0
Predator-Beetles												
<i>Micraspis</i> sp	1	7	3	6	6	8	0	1	1	1	0	2
<i>Menochilus sexmaculatus</i>	5	13	7	21	11	24	11	20	10	27	15	19
<i>Harmonia</i> sp	3	0	2	0	1	1	1	4	3	1	9	4
Predator-Spiders												
Amaurobiidae sp	0	0	0	0	0	0	0	0	0	1	2	2
Clubionidae sp	1	1	1	5	3	15	4	1	3	9	5	4
Gnaphosidae sp1	0	0	0	0	1	0	0	3	0	0	0	0
Gnaphosidae sp2	0	0	0	0	0	0	1	0	7	0	0	0
Lycosidae sp1	1	1	1	0	0	0	0	0	0	11	8	1
Lycosidae sp2	2	0	0	5	2	9	5	0	1	0	0	0
Miturgidae sp1	1	2	0	0	0	0	0	0	0	0	0	0
Miturgidae sp2	0	1	2	0	0	0	4	0	1	0	0	0
Parasitoid wasp												
<i>Telenomus</i> sp	0	0	0	74	0	0	0	0	1241	0	0	45
Mymaridae sp	0	0	0	0	0	0	0	0	1	0	0	0

In conclusion, the invasion of *S. frugiperda* can reduce the attack intensity of native lepidopteran pests and also reduced the diversity of natural enemies especially predators. *S. frugiperda* can co-inhabit with native lepidopteran pests as an additional pest in maize fields across East Java. Since this study was conducted only a year after the introduction of *S. frugiperda*, further research will be needed to confirm the effect on local biodiversity as well as understand the interaction complexity with native natural enemies. The agroecological approach can be adopted to manage the infestation of *S. frugiperda* in new invaded habitat (Harrison et al. 2019). The management scale should be considered due to agricultural intensification at the landscape scale will be an advantage for *S. frugiperda* (Emery et al. 2021). In addition, intercropping maize with other crops should also be carefully counted due to intercropping with the wrong crop such as cassava (*Manihot esculenta*) may increase in *S. frugiperda* infestation due to encourages feeding and oviposition of the invasive pest on maize (Nwanze et al. 2021).

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