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RESEARCH PAPER

The population dynamics of *Spodoptera frugiperda* after its invasion in Lampung Province, Indonesia

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ABSTRACT

Spodoptera frugiperda is an invasive pest that attacks maize throughout Indonesia. As an invasive pest, the population of *S. frugiperda* continues to increase exponentially, leading to outbreaks. Both internal factors (biology) and external factors (weather, host, and natural enemies) can affect the growth rate of pest populations. This research was conducted to assess the population dynamics of *S. frugiperda* based on the extent of its infestation and damage to maize post-invasion in Lampung Province. Observations were made in maize fields in 15 districts of Lampung Province from 2019 to 2022. Damage intensity was calculated based on the leaf damage scale. Weather data from 2019 to 2022 was obtained from the Lampung Province Central Statistics Agency. The research results indicate that upon the initial introduction of *S. frugiperda* to Lampung Province, the population increased exponentially, as observed based on the level of infestation and damage to maize. There was an outbreak from late 2019 to early 2020, and after that, there was a population decline. The population increase coincided with the early rainy season, which is associated with the beginning of the maize planting season. Although the level of damage to the maize is considered slight, *S. frugiperda* can cause anywhere between 21.94% to 51.38% of damage.

Key words: infestation and damage, invasive pest, population dynamics, *Spodoptera frugiperda*

INTRODUCTION

Maize is a crucial commodity in Lampung Province, with an average production of 6 tons/ha, surpassing the national average (Astuti et al., 2021). The entry of *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) into Lampung Province has become a significant problem in maize cultivation. *S. frugiperda* is a pest originating from tropical regions in America (Luginbill, 1928). In 2016, this pest spread to several African countries (IITA, 2016), including Benin, Nigeria, Sao Tome and Principe, and Togo (Goergen et al., 2016), and then expanded to over 30 countries in Africa (Prasanna et al., 2018). In 2018, *S. frugiperda* was reported to attack maize in Karnataka, India (Sharanabasappa et al., 2018), Myanmar (Yee et al., 2019), Thailand, Sri Lanka (IPPC, 2018), and Yunnan, China (Huang et al., 2020). *S. frugiperda* has spread to countries in Asia (IPPC, 2018), including Indonesia (Trisyono et al., 2019). Attacks by *S. frugiperda* have been reported in West Sumatra (Nonci et al., 2019), Lampung (Trisyono et al., 2019), and West Java (Maharani et al., 2019). Currently, *S. frugiperda* is found throughout the corn production areas.

S. frugiperda is a polyphagous pest, having more than 100 host plants (Sharanabasappa et al., 2018). In Brazil, it is reported to have more than 353 host plants from 76 families (Montezano et al., 2018). *S. frugiperda* is found in wheat, sorghum, and millet (Hruska, 2019). While it also attacks sugarcane (Song et al., 2020), it prefers maize as its host plant (Hruska, 2019). Crop losses due to *S. frugiperda* infestation vary between countries. Losses in maize in Brazil range around 34.00% (Lima et al., 2009), in Zimbabwe 11.57% (Baudron et al., 2019), in Kenya more than 30.00% (Groote et al., 2020), in India 33.00% (Balla et al., 2019), in the United States 5–20% (Capinera, 2020), and in Zambia 35.00% (Rwomushana et al., 2018). *S. frugiperda* has become global concern and is known as a pest causing significant yield losses with substantial economic impacts (Koffi et al., 2020;

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Overton et al., 2021).

The population of *S. frugiperda* can be measured based on its infestation and damage to maize. The higher population of *S. frugiperda* is indicated by the higher damage to maize. As an invasive pest, the population of *S. frugiperda* has increased exponentially, leading to outbreaks. The invasion of *S. frugiperda* into Indonesia was not accompanied by its natural enemies, causing the population to increase rapidly. Both abiotic factors (temperature, humidity, light) and biotic factors (host, natural enemies, vegetative biodiversity, crowding and diets) significantly influence insects and their population dynamics (Khaliq et al., 2014; Stoner, 2024).

The presence of natural enemies is one of the limiting factors for the growth of the *S. frugiperda* population. However, the adaptation process of native natural enemies is necessary to effectively control the population of *S. frugiperda*, which is an invasive pest. The adaptation process of native natural enemies to attacking invasive pests takes varying amounts of time. One indicator that native natural enemies are beginning to attack the pest is the decrease in the pest population and a reduction in the level of plant damage. Therefore, it is necessary to study the population dynamics of *S. frugiperda* based on the extent of its infestation and damage to maize post-invasion in Lampung Province, Indonesia.

MATERIALS AND METHODS

Research Site. Data on the damage level of *S. frugiperda* were obtained from observations in 15 districts in Lampung Province from 2019 to 2022. The data on the damage intensity of maize were collected through surveys in four central corn-producing districts in Lampung Province, namely Pringsewu (-5º25'56.8"105º03'29.9"), Lampung Selatan (-5º22'48"105º23'55") Lampung Timur (-5º 03'51.076"105º21'42.364"), and Lampung Pesawaran (-5º22'7.579"105º12'13.08") from 2019 to 2022.

Morphological Identification. Morphological identification is necessary to ensure that the larvae found are *S. frugiperda*. The process of morphological identification is carried out following the method conducted by Lestari et al. (2020).

Observation of the Damage Based on Area Coverage. The observation of damage levels was conducted following the method described by the Directorate of Food Crop Protection (2018), with categories of slight damage (1–25% of plant damage), moderate (>25–50% of plant damage), severe (>50–85% of plant damage), and very severe (>85% of plant damage).

Weather Observation in Lampung Province. Rainfall, air humidity, and sunlight data from 15 districts in Lampung Province were obtained from the Central Statistics Agency of Lampung Province (2023).

Sampling of Damage Intensity Due to the Attack of *S. frugiperda* in Lampung Province. Sampling was conducted using the systematic sampling method on a one-hectare field. The distance from the field edge to the first sampled plant was approximately 10 m. Each plot consisted of four sections, with each section comprising 20 corn plants (Supplementary 1). Damage observations were made on plants approximately 35 days after planting, following the scale of Davis et al. (1992) (Table 1). For easier determination of the damage scale on leaves, reference can be made to the leaf damage illustration (Figure 1). Information on corn varieties was also recorded as supporting data. The damage data were then analyzed by calculating the attack intensity using the following formula:

$$I = \frac{\sum_{i=0}^{Z}(n_i \times v_i)}{Z \times N} \times 100\%$$

I = Intensity of damage;
n_i = Number of plants with damage scale v_i;
v_i = Value of the i-th damage scale;
Z = Total number of observed plants;
N = Highest damage scale value.

RESULTS AND DISCUSSION

Morphological Characteristics of *S. frugiperda*. The larvae of *S. frugiperda* have specific morphological characteristics that are found on the head and dorsal abdomen of the eighth segment. On the head, there is a line resembling an inverted Y (Figure 2A), distinguishing it from other *Spodoptera* genera, which generally have a V-shaped appearance. On the eighth segment of the abdomen, there are four pinacula arranged in a square (Figure 2B). On the lateral side of the larva's body, there are longitudinal lines resembling stripes (Figure 2C).

Eggs of *S. frugiperda* are laid in masses on the leaf surface. The eggs, colored yellowish-green, are covered with fine, dirty-white threads (Figure 3). They will hatch within three days. Although *S. frugiperda*

Table 1. Damage score on leaves of maize

No	Description
1	A pinhole damaged size;
2	A small circular hole of damage;
3	1.3 cm of longitudinal damage on the leaf;
4	1.3-2.5 cm of longitudinal damage on the leaf;
5	Irregular damage of more than 2.5 cm on the leaf;
6	Large, elongated, and irregular holes on the leaves;
7	Some longitudinal lesions of all sizes on the leaves;
8	Some longitudinal lesions of all sizes on the leaves and growing point;
9	The leaf rolls are almost completely destroyed.

Source: Davis et al. (1992).

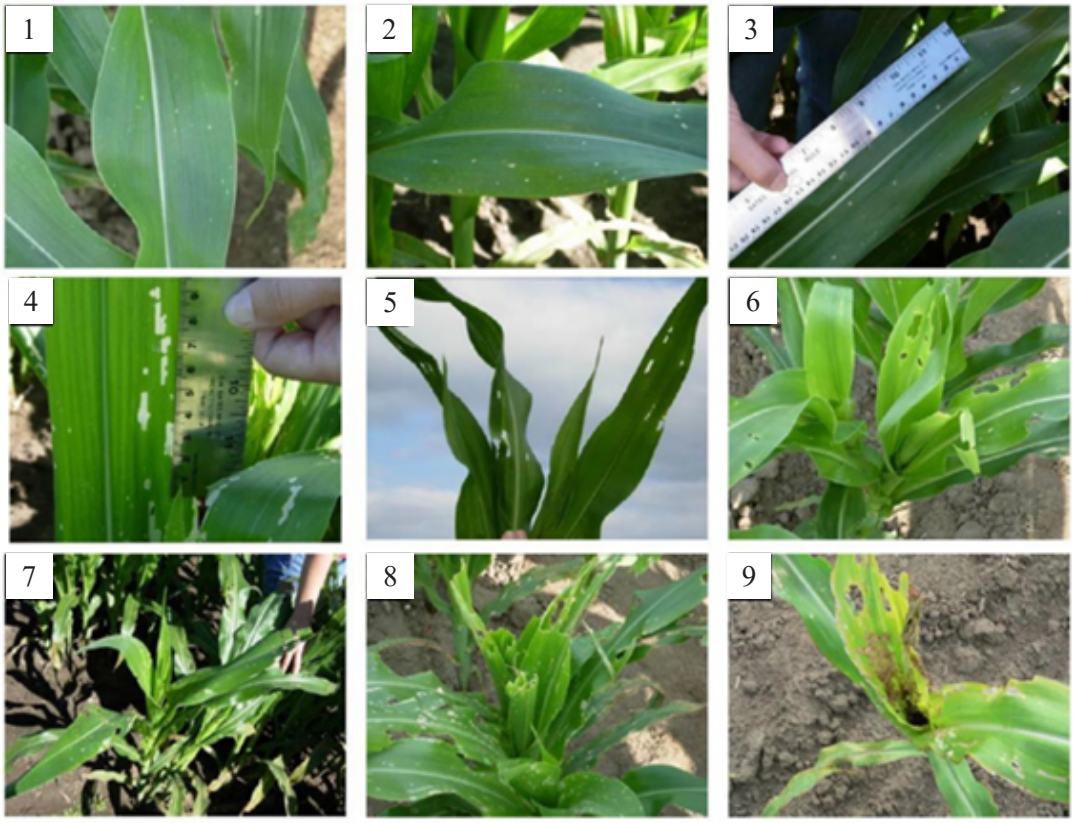


Figure 1. Davis scoring criteria on foliar damage by *Spodoptera frugiperda* (Source: Dupont Pioneer, Brazil in: IRAC, 2021).

Figure 2. Morphological characteristics of *S.podoptera frugiperda*. A= Y shape on the head; B= Pinacula arranged in a square shape on the eighth segment of abdomen; C= Longitudinal band-like lines on the lateral side.

Figure 3. The egg mass of *Spodoptera frugiperda* on the leaf surface of maize.

has specific characteristics, the morphology of early instars is often confusing between *S. frugiperda* and *S. exigua*. The difference is noticeable on the cuticle surface, as *S. frugiperda* has a granular cuticle, while *S. exigua* has a smoother cuticle (Passoa, 1991).

Infestation and Damage Levels of *S. frugiperda* on Maize Based on Cultivation Area in Lampung Province. *S. frugiperda* is a polyphagous insect that was first reported attacking maize in West Sumatra and subsequently spread widely throughout maize in Indonesia, including in Lampung Province, Banten, West Java, East Java (Trisyono et al., 2019; Rizali et al., 2021; Sartiami et al., 2020). The spread of *S. frugiperda* has occurred rapidly; however, it is not clear how it has spread to the island of Sumatra. *S. frugiperda* massively attacks maize. The quick spread of *S. frugiperda* is supported by its high migration and dispersal abilities (Meagher et al., 2004; Kumela et al., 2018).

In less than a year after the invasion in Lampung Province, the *S. frugiperda*-affected maize cultivation area in Lampung Province increased by more than 100%, reaching 14,435.5 ha of affected area (Figure 4). The population of *S. frugiperda* has a significant impact on the damage level. The higher the pest population, the higher the damage level will be. The expansion of the affected area occurred because the spread of *S. frugiperda* from its origin country was not followed by the dispersion of its natural enemies (Sari et al., 2023). As a consequence, there was an uncontrollable increase in population in the invaded area. Additionally, *S. frugiperda* has a strong ability to adapt to new environments (CABI, 2019). As the third-largest corn-producing region in Indonesia, maize can be found in Lampung Province throughout the year, significantly supporting the survival of *S. frugiperda*.

The outbreak of *S. frugiperda* occurred in late 2019 and early 2020 (Figure 4) due to the absence of native natural enemies that had not yet adapted. In addition, the onset of the rainy season provided highly favorable conditions for *S. frugiperda*. After the outbreak, the population of *S. frugiperda* decreased one year post-invasion, specifically in March 2020. A population decrease may indicate the presence of natural enemies that have adapted to the invasive pest, acting as a limiting factor to the exponential population growth. Several parasitoids have been reported for their parasitic activities in Indonesia. *Telenomus* sp. has been reported to parasitize *S. frugiperda* eggs mass (Sari et al., 2021; Suci et al., 2021; Herlinda et al., 2023). Some larval parasitoids have been reported, namely *Chelonus formosanus*, *C. annulipes, C. oculator, C. cautus, Microplitis manilae*, and *M. marshallii* (Herlinda et al., 2023; Sari et al., 2023).

Environmental factors have a significant impact on the development of *S. frugiperda* (Feldmann et al., 2019). The dynamics of the population of the invasive pest are influenced not only by the activity of native natural enemies but also by climatic conditions and the availability of host plants. After experiencing a decline, the population of *S. frugiperda* increased in October 2020. In Figure 5, it can be seen that the increase in population was characterized by widespread attacks, which occurred at the same time as increased rainfall. This is related to the availability of maize as the primary host for *S. frugiperda*. The population of *S. frugiperda* is believed to depend on several factors throughout the year, including weather conditions and the availability of host plants (Mitchell, 1979). The early rainy season marks the beginning of the maize planting season, which is the main host for *S. frugiperda*. Food sources and temperature are essential factors in insect dispersal, in addition to environmental factors (Price, 1997; Shi

et al., 2012).

Climate conditions influence the dynamics of pest populations (Diyasti & Amalia, 2021). Temperature is a dominant abiotic factor influencing the distribution, phenology, and natural enemies of *S. frugiperda* (Yan et al., 2022). The population of *S. frugiperda* tends to increase with rising temperatures (Baloch et al., 2020). In Indonesia, a tropical country with no significant temperature difference between seasons, Figure 5 showed average daily temperatures in Lampung Province ranging from 27 to 34 °C in the years 2019–2022 (Central Statistics Agency of Lampung Province, 2023). This relatively warmer temperature condition supports the development of the *S. frugiperda* population, thus contributing to the damage. Despite an increase in rainfall, the average air temperature remains relatively stable throughout the year, making this condition highly favorable for *S. frugiperda*.

S. frugiperda was reported to attack maize across all planting areas in Lampung Province, with the categories of damage ranging from slight to

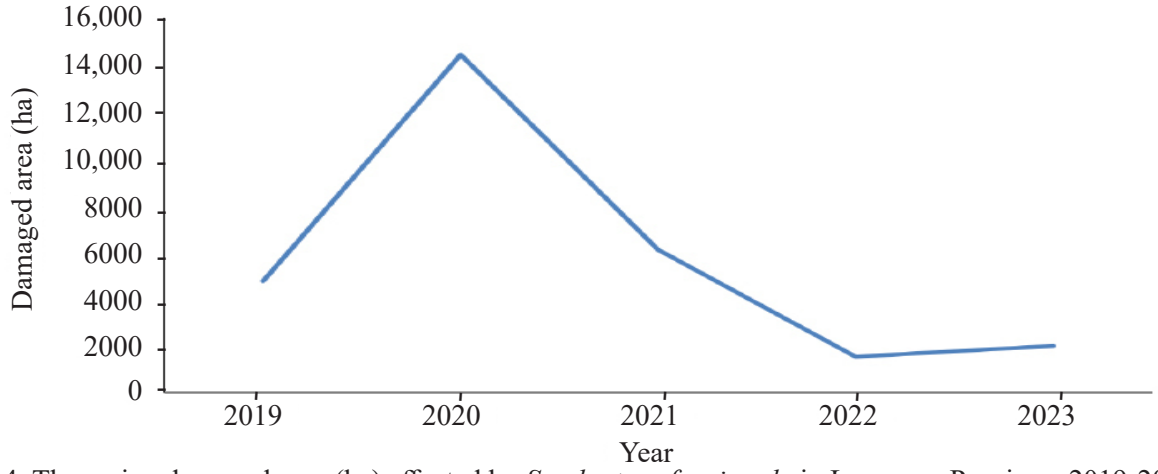


Figure 4. The maize-damaged area (ha) affected by *Spodoptera frugiperda* in Lampung Province, 2019-2022.

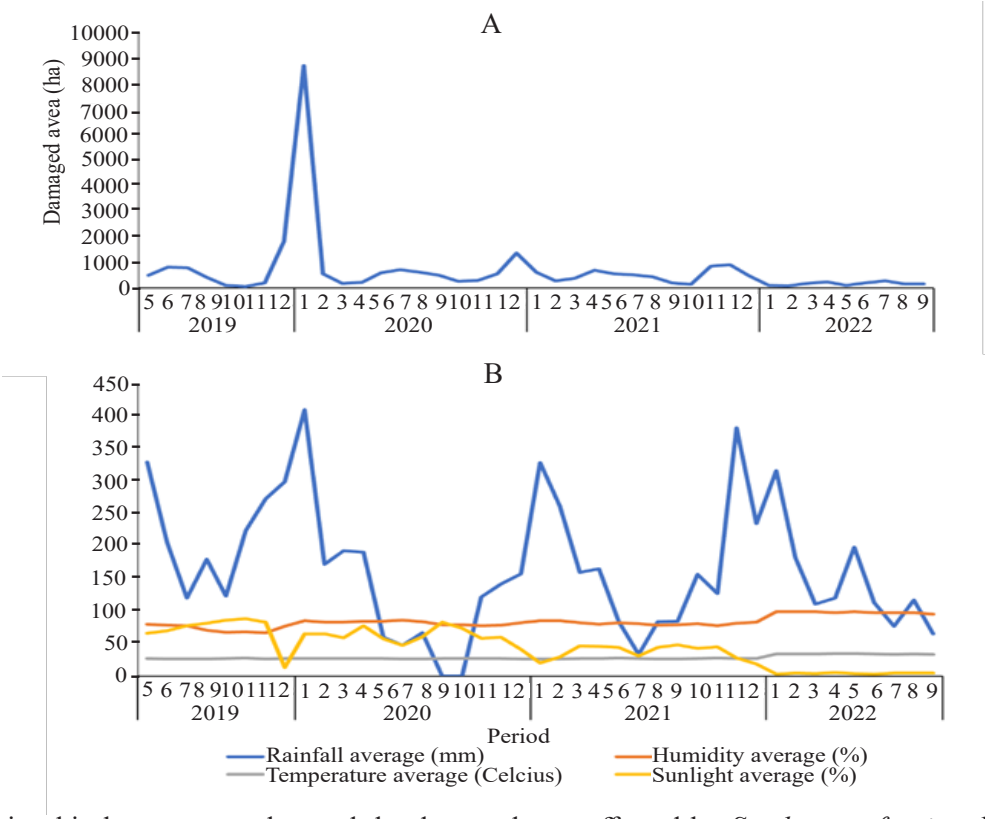


Figure 5. Relationship between weather and the damaged area affected by *Spodoptera frugiperda* attacks; A= Maize-damage area in Lampung Province; B= Lampung Province weather data (Source: Central Statistics Agency of Lampung Province, 2023).

very severe. The level of *S. frugiperda* attack was calculated based on the percentage of plant damage in an observed field, following the categories described by the Directorate of Food Crop Protection (2018): slight (1–25% of plant damage), moderate (>25–50% of plant damage), severe (>50–85% of plant damage), and very severe (>85% of plant damage). Based on the obtained data, the majority of *S. frugiperda* attacks belong to the category of slight (Figure 6), with the largest affected areas found in the Lampung Selatan and Lampung Tengah Districts (Figure 7). The large area affected was also in line with the size of the maize planting area.

The Intensity of Damage Due to the *S. frugiperda* Attack in Lampung Province. Although, in general, the level of maize damage falls into the slight category, i.e., ≤ 25% of the affected area, the intensity of damage in the field varies significantly (Table 2). Similarly to the affected area, the intensity of damage also fluctuates.

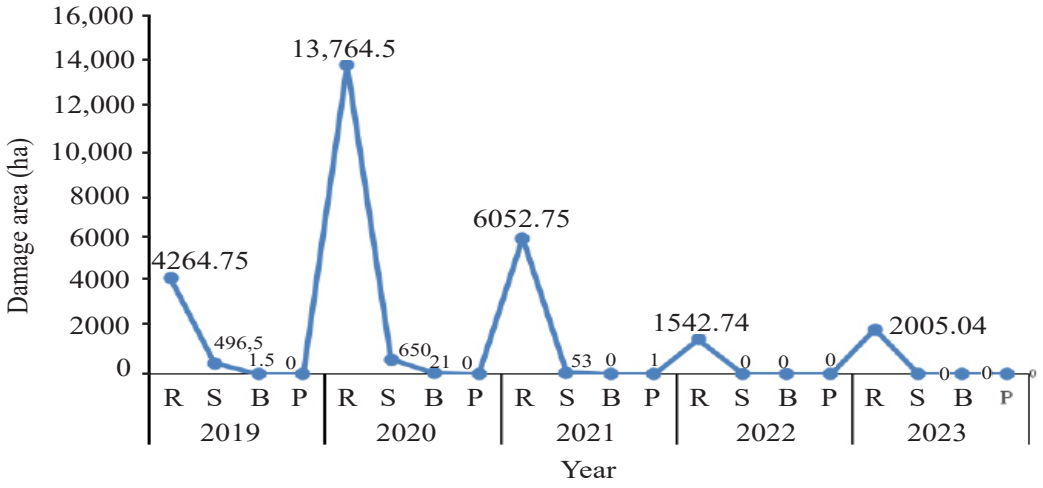


Figure 6. Damaged area caused by *Spodoptera frugiperda* in Lampung during 2019-2022. R= Slight damage (1 to ≤ 25% of plant damage); S= Medium damage (> 25 to ≤ 50% of plant damage); B= Severe damage (> 50 to ≤ 85% of plant damage); P= Crop failure (> 85% of plant damage).

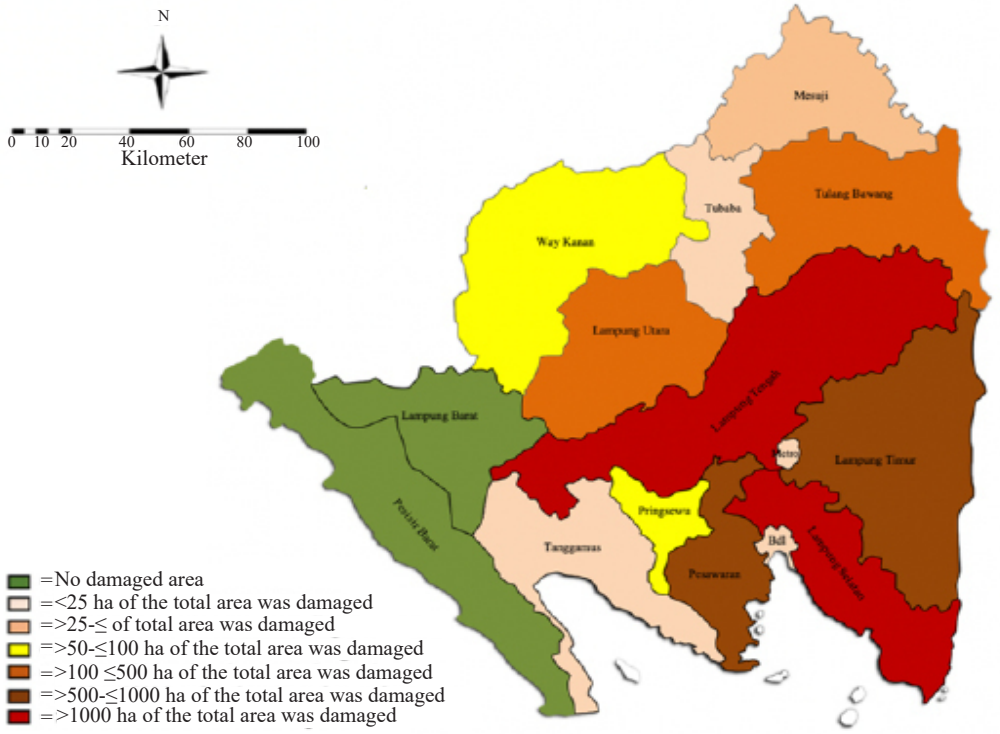


Figure 7. The extent of maize plant damage caused by Spodoptera frugiperda in Lampung Province.

Table 2. Damage intensity on maize due to *Spodoptera frugiperda* attacks in four districts of maize production centers in Lampung Province

Districts	Damage intensity (%)				
	2019	2020	2021	2022	2023
Pringsewu	50.64	51.38	45.83	42.59	60.87
Lampung Selatan	21.94	46.29	31.89	26.29	63.33
Pesawaran	32.59	50.64	44.95	41.94	56.94
Lampung Timur	50.37	50.78	47.63	45.87	52.17

Figure 8. Damage on maize caused by *Spodoptera frugiperda*; A= Severe damage in Pringsewu District (-5º25'56.8"105º03'29.9"); B= Crop failure in Lampung Selatan District (-5º22'48"105º23'55").

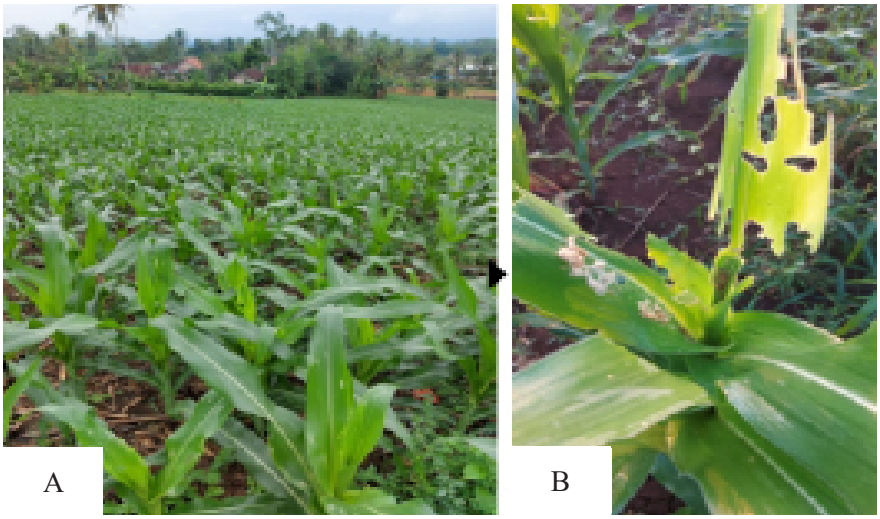
At the onset of the invasion, the intensity ranged from 21.94% to 51.38%. It then decreased in 2021 and 2022, with the highest damage intensity recorded at 47.63% in Lampung Timur District. However, in 2023, the intensity of damage increased to 63.33%. Observations conducted in four districts show that almost all plants in the sample plots in Pringsewu District suffered severe damage (Figure 8A), and in Lampung Selatan District, the damage was severe, extending to crop failure (Figure 8B). Additionally, there is a strong suspicion that *S. frugiperda* has developed resistance to insecticides. Further research on insecticide resistance is needed.

S. frugiperda attacks all stages of maize (Chimweta et al., 2020). The observation of damage intensity following the Davis et al. (1992) was conducted on maize aged 45 days after planting. In the vegetative stage, adults of *S. frugiperda* begin laying eggs on corn plants aged 7–45 days after planting, resulting in symptoms that vary depending on larval stages. Upon entering the generative stage, adults of *S. frugiperda* lay eggs on silk, disrupting the fertilization and pollination processes, causing damage to tassels and boreholes in the kernel. Furthermore, it can decrease the harvest quality and lead to secondary infection of the kernel (Anjorin et al., 2022). *S. frugiperda* attacks on maize plants are sporadic. In one field, larvae of different instars are often found, leading to variations in damage severity. Early instar larvae of *S. frugiperda* typically cause minor damage intensity. The first instar larvae will feed on the leaf surface, creating longitudinal transparent lines (Figure 9A), induce severe symptoms by feeding on the leaves at the growing point. Symptoms of damage become visible when the leaves have unfolded (Figure 9B).

The difference in planting time makes *S. frugiperda* population control strategies challenging. In one area, the planting time difference might vary from five to forty days, even if the planting season begins at the start of the wet season. This means that *S. frugiperda* has hosts that are constantly available. Furthermore, adults of *S. frugiperda* can fly great distances, up to 100 km in a night, which facilitates migration to corn plantings that are ideal for its development (CABI, 2019; FAO, 2017).

CONCLUSION

This research concludes that, at the onset of *S. frugiperda* in Lampung Province, the population of *S. frugiperda* continues to increase exponentially because the native natural enemies have not adapted to attack *S. frugiperda*. Rainfall has an impact on *S. frugiperda* populations. The population dynamics of *S. frugiperda* can be observed in the extent of the *S. frugiperda* attack area, with the peak population occurring at the



A B

Figure 9. The symptoms of *Spodoptera frugiperda* attack on maize plants. A= Early instar-induced damage; B= Further symptoms of the attack.

beginning of the rainy season. However, temperature and humidity in Lampung Province do not affect the population dynamics of *S. frugiperda*.

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AUTHORS' CONTRIBUTIONS

PL was responsible for conducting research and drafting the article; RS was responsible for providing research ideas; YF was responsible for controlling the research and data analysis; IGS drafted the article; SDU was responsible for proofreading the article; and MH was responsible for data collection.

COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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