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RESEARCH PAPER

Infestation of *Spodoptera frugiperda* on corn in Bengkulu at different elevations

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ABSTRACT

Pest infestation is a significant challenge in corn cultivation due to the potential damage it can cause, leading to reduced crop productivity or even complete crop failure. This study aims to assess the infestation of *Spodoptera frugiperda* on corn in Bengkulu, considering various elevations. Ten hybrids resulting from crosses between promising lines (Caps 2 x Caps 17A, Caps 3 x Caps 17A, Caps 3 x Caps 17B, Caps 5 x Caps 22, Caps 5 x Caps 17B, Caps 15 x Caps 22, Caps 17B x Caps 23, Caps 17A x Caps 17B, Caps 17A x Caps 22, Caps 22 x Caps 23) and three commercial hybrid varieties (Bonanza, Paragon, and Secada) were evaluated across three locations at different elevations: lowland (30 meters above sea level) (masl), midland (600 masl), and highland (1000 masl). The assessment focused on the extent of damage and the plant's resistance to *S. frugiperda* infestations. The infestation of *S. frugiperda* is higher at an elevation of 30 masl compared to locations at 600 masl and 1000 masl. Scoring leaf damage caused by *S. frugiperda* infestation at 30 masl: 2.73–4.86, at 600 masl: 2.73–3.55, and at 1000 masl: 2.4–3.37.

Key words: corn, pest, hybrid, resistant, susceptible

INTRODUCTION

Spodoptera frugiperda J.E. Smith (Lepidoptera: Noctuidae) or the fall armyworm (FAW), is an invasive pest in Indonesia that targets corn plants (Maharani et al., 2019; Trisyono et al., 2019; Lestari et al., 2020; Herlinda et al., 2022). Originally from South America, *S. frugiperda* entered Africa in 2016 and rapidly spread to Asia, reaching Korea and Japan by 2019 (Goergen et al., 2016; Jing et al., 2020; Lee et al., 2020). This polyphagous pest causes significant economic losses in various agricultural commodities such as corn, rice, wheat, sorghum, legumes, potatoes, and cotton (Day et al., 2017).

The damage caused by *S. frugiperda* in Africa can lead to a reduction in corn production by approximately 8.3–20.6 million tons per year, equivalent to 2,481–6,187 million USD per year (Shylesha et al., 2018). Baudron et al. (2019) also reported *S. frugiperda* infestations in corn ranging from 26.4% to 55.9%, resulting in an 11.57% decrease in yield. Leaf, silk, and ear damage ranging from 25% to 50% led to a 58% reduction in yield (Chimweta et al., 2019; Sisay et al., 2019). Various insecticides have been applied to control *S. frugiperda*; however, chemical control has not been effective, as the pest has developed resistance to commonly used insecticides such as Lambda-cyhalothrin, Chlorpyrifos, Spinosad, and Lufenuron (Carvalho et al., 2013; do Nascimento et al., 2016).

The biology, distribution, and abundance of pests are largely influenced by temperature. Changes in temperature can impact their developmental rate, life cycle, and survival (Tobin et al., 2003). The optimal temperature range for the development of eggs, larvae, and pupae to the adult stage of *S. frugiperda* is between 26 ºC and 30 ºC. The fastest larval development and lowest mortality occur at 30 ºC (Du Plessis et al., 2020). Deviations from this optimum range, either lower or higher, can lead to a decrease in the developmental rate (Begon et al., 2006). Temperature also affects the duration of each instar and the number of instars that larvae go through before reaching the adult stage (Aguilon et al., 2015). Faster developmental rates are advantageous for insects, as they spend less time in vulnerable stages and are less likely to be attacked by predators, parasitoids, and entomopathogens (Jaworski & Hilszczański, 2013).

Sustainable control of FAW requires the implementation of integrated pest management

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strategies, with host plant resistance being a key component (Sodiq, 2009). Significant progress has been made in breeding maize hybrids with genetic resistance to *S. frugiperda* in Africa. These efforts have been intensified by the development and dissemination of maize cultivars that are tolerant or resistant to *S. frugiperda* and suitable for diverse agroecological regions in Africa, Asia, and other countries. In some cases, traditional breeding for *S. frugiperda* resistance has been largely replaced by the adoption of Bt maize (Knolhoff & Heckel, 2014). Bt maize exhibits resistance to *S. frugiperda*, constituting over 85% of maize production in America, Brazil, and Argentina (Andama et al., 2020). Nevertheless, the use of Bt maize encounters challenges in certain countries due to high seed costs and low maize prices received by small-scale farmers (Wightman, 2018).

Therefore, there is a need for research on the infestation of *S. frugiperda* on hybrid sweet corn in Bengkulu across different elevations. This information is vital for farmers, breeders, seed companies, and policymakers to identify suitable cultivars for their respective regions and contribute to *S. frugiperda* resistance breeding efforts. Consequently, understanding the impact of temperature on the development of insect species becomes crucial for risk analysis, forecasting, and management strategies aimed at minimizing pest infestations. The objective of this study was to assess the infestation of *S. frugiperda* on corn in Bengkulu at various elevations.

MATERIALS AND METHODS

Research Site. The study was conducted from October 2021 to March 2022 at different elevations: lowland (30 meters above sea level) (masl) in Kandang Mas, Kampung Melayu, Bengkulu City; midland (600 masl) in Taba Mulan Village, Merigi District, Kepahiang Regency; and highland (1000 masl) in Sambirejo Village, Selupu Rejang District, Rejang Lebong Regency. Cumulative rainfall (October 2021–March 2022) in the area of Rejang Lebong and Bengkulu City (1501–2000 mm) was classified as normal, with rainfall values between 85–115%. Meanwhile, the Kepahiyang area has less than average or below normal rainfall, which was less than 85% (BMKG, 2021).

Research Design. This study employed a Randomized Complete Block Design (RCBD) with ten hybrids resulting from the crossing of promising lines (experimental hybrids): Caps 2 x Caps 17A, Caps 3 x Caps 17A, Caps 3 x Caps 17B, Caps 5 x Caps 22, Caps 5 x Caps 17B, Caps 15 x Caps 22, Caps 17B x Caps 23, Caps 17A x Caps 17B, Caps 17A x Caps 22, Caps 22 x Caps 23, along with three conventional hybrid varieties for comparison, namely Bonanza, Paragon, and Secada. Each treatment was replicated three times, with 12 sample plants per treatment unit.

Land Preparation and Planting Corn Seeds. Land preparation involved clearing existing vegetation and cultivating the soil using hand tools. Subsequently, the area was divided into experimental plots, each measuring 1.5 × 5 m. The spacing between these plots was 50 cm, while the spacing between blocks or replications was 100 cm. Planting was executed using dibbles, with one seed per planting hole, and a planting distance of 75 × 25 cm, resulting in 40 plants per plot. Fertilizer application consisted of Urea, SP-36, and KCl at doses of 50 kg per ha, 50 kg per ha, and 25 kg per ha, respectively. A blend of Urea, SP-36, and KCl fertilizers was placed in furrows that were 5 cm deep and located 7 cm away from the planting holes, after which they were covered with soil.

Larval Population and Leaf Damage Caused by *S. frugiperda*. The larvae population was observed by counting the number of larvae found, the number of plant sample units was 4 plants per plot. Observations were carried out 4 times at intervals once a week, and observations began when the plants were 4 weeks old. Plant damage expressed by the Davis score is used to measure plant resistance (Davis & Williams, 1992). In this system, a score of 1 was assigned to highly resistant plants showing no damage, while a score of 9 indicated highly susceptible plants that suffered severe damage (Table 1; Figure 1).

RESULTS AND DISCUSSION

Symptoms of *S. frugiperda* infestation commence with rolled leaves, and the larvae feed on the leaves of hybrid corn plants, progressing toward the plant's growing point. Consequently, infested leaves of hybrid corn plants develop holes, and their edges become ragged. Intense larval feeding can lead to the severing of the plant's growing point. The feeding activity of *S. frugiperda* larvae also leaves behind sawdust-like frass. The infestation of *S. frugiperda* is higher at an elevation of 30 masl compared to locations at 600 meters and 1000 masl. Scoring leaf damage caused by *S. frugiperda* infestation 30 masl ranges from 2.73 to 4.86, at 600 masl it ranges from 2.73 to 3.55, and at 1000 masl it ranges from 2.4 to 3.37 (Table 2).

Table 1. The scoring criteria for assessing leaf damage caused by *S. frugiperda* infestation

Score	Description	Respond
1	No visible leaf-feeding damage;	Highly Resistance
2	Few pinholes on 1-2 older leaves;	Resistance
3	Several shot-hole injuries on a few leaves (<5 leaves) and small circular hole damage to leaves;	Resistance
4	Several shot-hole injuries on several leaves (6–8 leaves) or small lesions/ pinholes, small circular lesions, and a few small elongated (rectangular-shaped) lesions of up to 1.3 cm in length present on whorl and furl leaves;	Partially resistant
5	Engated lesions (>2.5 cm long) on 8-10 leaves, plus a few small to mid-sized uniform to irregular-shaped holes (basement membrane consumed) eaten from the whorl and/or furl leaves;	Partially resistant
6	Several large elongated lesions are present on several whorl and furl leaves and/ or several large uniform to irregular-shaped holes eaten from furl and whorl leaves;	Susceptible
7	Many elongated lesions of all sizes are present on several whorl and furl leaves plus several large uniforms to irregular-shaped holes eaten from the whorl and furl leaves;	Susceptible
8	Many elongated lesions of all sizes are present on most whorl and furl leaves plus many mid- to large-sized uniform to irregular-shaped holes have eaten from the whorl and furl leaves;	Highly Susceptible
9	Whorl and furl leaves were almost totally destroyed and plants dying as a result of extensive foliar damage.	Highly Susceptible

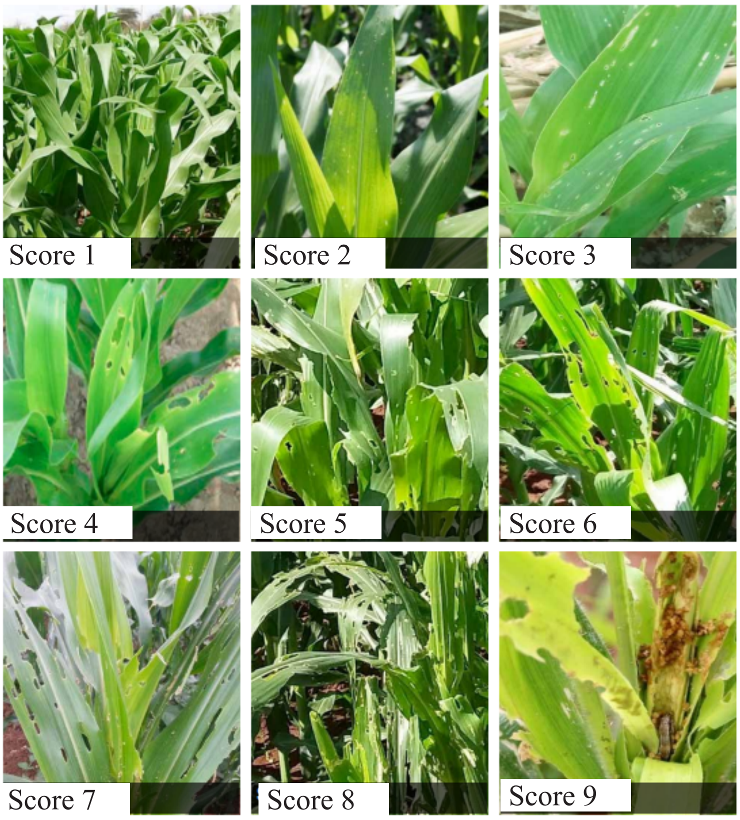

Figure 1. Scoring criteria on foliar damage by FAW (Prasanna et al., 2018).

The resistance of different hybrid corn varieties to *S. frugiperda* infestation varies at an elevation of 30 masl. Varieties such as Caps 3 x Caps 17B, Caps 15 x Caps 22, Caps 17A x Caps 17B, Caps 17A x Caps 22, and Caps 22 x Caps 23 exhibit moderate resistance, while varieties including Caps 2 x Caps 17A, Caps 3 x Caps 17A, Caps 5 x Caps 22, Caps 5 x Caps 17B, Caps 17B x Caps 23, Bonanza, Paragon, and Secada are classified as resistant (Table 2). At an elevation of 600 masl, during plant ages ranging from 4 to 7 weeks after planting, all hybrid maize types demonstrate resistance to *S. frugiperda* infestation (Table 3). Similarly, at an elevation of 1000 masl and with plant ages ranging from 4 to 7 weeks after planting, all corn types exhibit resistance to *S. frugiperda* infestation (Table 4).

The resistance traits displayed by plants are inherent (inherited genetic factors), although they can also be influenced by environmental conditions that foster relative resistance to pest attacks. Some experts classify plant resistance into two groups: ecological resistance and genetic resistance (Kogan, 1982). Other experts consider ecological resistance not as true resistance but rather as false or pseudo resistance, while genetic resistance is deemed the genuine resistance trait of plants. This distinction arises because ecological resistance traits are not fixed and can readily change based on environmental conditions, whereas genetic resistance traits are relatively stable and less influenced by environmental shifts.

Elevation influences the development of pests and their host plants, wherein temperature plays a significant role in the presence and development of pests within an ecosystem. This is because each pest species possesses its own temperature tolerance within the ecosystem. The biology, distribution, and abundance of pests are significantly affected by the interplay between temperature and the rate of their life cycle development and survival (Tobin et al., 2003).

Screening for corn resistance varieties against FAW infestation is based on the level of plant damage. Resistant varieties are characterized by experiencing less damage compared to other varieties under the same environmental conditions. At an elevation of 30 masl, the varieties Caps 3 x Caps 17B, Caps 15 x Caps 22, Caps 17A x Caps 17B, Caps 17A x Caps 22, and Caps 22 x Caps 23 are considered moderately resistant, while the remaining varieties are classified as resistant (Table 2). This phenomenon is believed to be influenced by various bio-physical and biochemical factors, including morphological and anatomical traits, as well as the composition of compounds present in these plants.

According to Hedin et al. (1996), resistant corn varieties exhibit higher levels of hemicellulose and cellulose compared to susceptible corn plants concerning FAW resistance. Lipids on the leaf cuticle of corn contribute to the activity of FAW larvae. When FAW larvae consume leaves with removed lipids, they undergo faster development than larvae that feed on leaves containing lipids on the cuticle (Yang et al., 1993). In another study, neonate FAW larvae demonstrated longer travel distances and faster

Table 2. Number of larvae and leaf damage scoring due to *S. frugiperda* attack on hybrid corn at 30 meters above sea level

No	Corn hybrid variety	Average number of larvae	Average score	Respond
1	Caps 2 x Caps 17A	2.00 ab	3.68	Resistant
2	Caps 3 x Caps 17B	2.66 b	4.86	Partially Resistant
3	Caps 3 x Caps 17A	2.66 b	3.90	
4	Caps 5 x Caps 22	0.66 ab	3.57	Resistant
5	Caps 5 x Caps 17B	2.00 ab	3.35	
6	Caps 15 x Caps 22	2.00 ab	4.21	Partially Resistant
7	Caps 17B x Caps 23	0.33 a	2.75	Resistant
8	Caps 17A x Caps 17B	1.00 ab	4.10	
9	Caps 17A x Caps 22	1.00 ab	4.20	Partially Resistant
10	Caps 22 x Caps 23	0.66 ab	4.18	
11	Bonanza	1.66 ab	2.73	
12	Paragon	0.66 ab	3.23	Resistant
13	Secada	1.66 ab	3.75	

movement on smooth leaves compared to leaves with densely packed wax crystal structures (Yang et al., 1993).

Physical characteristics of plant tissues and toxic secondary metabolites also influence host plant selection behavior, forming a part of the plant's direct defense mechanism. Examples of these factors include trichomes, wax crystal structures, leaf thickness and toughness, and silica content, which can induce avoidance behavior in insects (Schoonhoven et al., 2005).

The process of insect host selection and acceptance involves multiple behaviors (Knolhoff & Heckel 2014; Schoonhoven et al., 2005). Initially, when an insect comes into contact with a plant, it assesses the physical and chemical condition of the plant to make an initial behavioral decision whether to continue or reject the plant. During this evaluation

Table 3. Number of larvae and leaf damage scoring due to *S. frugiperda* attack on hybrid corn at 600 meters above sea level

No	Corn hybrid variety	Average number of larvae	Average score	Respond
1	Caps 2 x Caps 17A	1.83 a	3.13	
2	Caps 3 x Caps 17B	2.00 a	3.20	
3	Caps 3 x Caps 17A	1.66 a	2.93	
4	Caps 5 x Caps 22	2.41 a	2.73	
5	Caps 5 x Caps 17B	2.50 a	3.15	
6	Caps 15 x Caps 22	2.83 a	3.27	
7	Caps 17B x Caps 23	2.00 a	3.06	Resistant
8	Caps 17A x Caps 17B	2.08 a	3.55	
9	Caps 17A x Caps 22	2.50 a	3.38	
10	Caps 22 x Caps 23	2.16 a	3.45	
11	Bonanza	2.16 a	3.08	
12	Paragon	1.66 a	2.83	
13	Secada	1.50 a	3.06	

Table 4. Number of larvae and leaf damage scoring due to *S. frugiperda* attack on hybrid corn at 1000 meters above sea level

No	Corn hybrid variety	Average number of larvae	Average score	Respond
1	Caps 2 x Caps 17A	1.41 a	2.50	
2	Caps 3 x Caps 17B	2.00 ab	2.61	
3	Caps 3 x Caps 17A	2.50 ab	2.38	
4	Caps 5 x Caps 22	2.66 b	2.46	
5	Caps 5 x Caps 17B	1.91 ab	2.56	
6	Caps 15 x Caps 22	2.08 ab	3.37	
7	Caps 17B x Caps 23	2.58 b	2.52	Resistant
8	Caps 17A x Caps 17B	2.75 b	3.06	
9	Caps 17A x Caps 22	1.91 ab	2.52	
10	Caps 22 x Caps 23	2.33 ab	2.38	
11	Bonanza	2.12 ab	2.29	
12	Paragon	2.25 ab	2.40	
13	Secada	2.41 ab	2.69	

phase, the insect restricts its movement to a smaller area. The subsequent step involves plant damage through probing and biting tests. When sensory information is positively evaluated by the insect's nervous system, a final decision is made, leading to the acceptance of the host plant (Schoonhoven et al., 2005). Furthermore, lipophilic constituents on the leaf surface (such as alkenes, esters, and fatty acids) and plant secondary metabolites are also recognized for their role in the probing and feeding behavior of insects (Schoonhoven et al., 2005).

Since the acceptance of a host plant is determined by the balance between stimulatory and inhibitory compounds, a comprehensive analysis of compounds within leaf tissues is necessary for host plant selection and preference. Flavonoid-C-glycosides and chlorogenic acid have been found to play crucial roles in the antibiosis activity of corn plants (Smith, 1994). Other studies have demonstrated the significance of leaf toughness in corn resistance to the European corn borer, *Ostrinia nubilalis* Hübner (Crambidae). It was discovered that leaf toughness serves as a significant defense mechanism in corn across various germplasm groups (Bergvinson et al., 1994).

At elevations of 600 masl and 1000 masl, all varieties were categorized as resistant to FAW infestation (Table 3 and Table 4). Evaluating corn plant resistance to FAW in the field is a more intricate process, given the plant's interactions with various factors, including location, soil type, plot size, agroecological conditions, weeding frequency, use of boundary plants, intercropping, manure application, and nitrogen (Baudron et al., 2019; Ni et al., 2013). It is important to also consider environmental conditions and the abundance of predator insects when assessing corn cultivar resistance to FAW and other insects in the field (Ni et al., 2013). While beetles, earwigs, and spiders are known as significant predators of FAW (Sueldo et al., 2010), we did not conduct sampling of predator arthropods in our research.

Further studies have delved into the role of indirect defense against FAW in corn. Several investigations have demonstrated that certain corn cultivars produce volatile organic compounds (VOCs) that attract insect parasitoids upon plant damage (Tamiru et al., 2012), or even volatiles released by plants as self-defense mechanisms (Roque-Romero et al., 2020). In corn plants, VOCs are not only essential for attracting parasitoids but also for drawing in insect predators (Ockroy et al., 2001). *Spodoptera littoralis* Boisduval (Noctuidae), for instance, is attracted to nine plant volatiles, highlighting the role of plant chemicals in larval behavior during the search for host plants (de Fouchier et al., 2018).

The infestation of *S. frugiperda* is higher at an elevation of 30 masl compared to locations at 600 masl and 1000 masl, and this variation is influenced by environmental factors. According to Kalshoven (1981), low environmental humidity and warm temperatures create ideal conditions for the development of *Spodoptera*. Insects are poikilothermic species, which means their body temperature depends on the ambient air temperature, consequently affecting their metabolic processes. As noted by Mavi & Tupper (2004), insect activity is faster and more efficient at higher temperatures.

Temperature exerts influence over pests by governing their development, survival, and spread (Koesmaryono, 1999). Each insect species possesses a specific temperature range requisite for its survival, and this range varies among different species. Insects' development and activity revert to normalcy when the air temperature falls within the suitable range (Mavi & Tupper, 2004).

Rainfall exerts both direct and indirect impacts on insects. Raindrops can physically disrupt their habitats, while rainfall also influences humidity and soil conditions indirectly. Both excessively low and high humidity levels can affect various aspects, including egg-hatching rates, larval survival, adult oviposition rates, and the emergence of Noctuidae insects. The distribution of rainfall throughout the year follows specific patterns, indicating the duration of wet periods with high rainfall and dry periods with low rainfall. The population explosion of a pest is closely linked to the periodicity of rainfall distribution (Koesmaryono, 1999). Moreover, high rainfall can directly lead to insect mortality or facilitate the development of insect pathogens (Mavi & Tupper, 2004).

Another defense mechanism in corn involves defense genes (Chuang et al., 2014). The variation in plant resistance to damage caused by *S. frugiperda* infestation in different corn varieties is also influenced by the genetic makeup of the plants. Transgenic or genetically engineered corn is a strategy to control FAW damage by expressing resistance genes against Lepidoptera. FAW-resistant corn varieties have been developed using crystal protein genes (cry) isolated from *Bacillus thuringiensis* (Bt). FAW larvae die after consuming cry proteins. Several cry genes, such as *cry1A, cry1Ab*, and *cry1F*, have been incorporated into Bt corn varieties (Horikoshi et al., 2016).

Plant resistance mechanisms against FAW infestation have also been enhanced in corn by increasing the thickness of the leaf epidermis (Davis et al., 1995). Viana et al. (2014) compared the resistance levels of 32 conventional hybrid corn varieties to FAW infestation with three Bt transgenic hybrids expressing cry1F and cry1A.105 + cry2Ab2 toxins (2B707Hx, AG8088PRO, and DK390PRO). The six most effective conventional hybrids had Davis scores ranging from 2.8 to 4.1, while the three Bt hybrids scored 1. In contrast, the susceptible control hybrids scored 7.

The observed corn varieties in Bengkulu in this study are predominantly conventional hybrids that show resistance to FAW infestation. Therefore, it is important to continue developing and planting these corn varieties. However, further research is necessary, as this study did not measure the morphology and chemical compounds of the plants that could potentially impact FAW infestation.

CONCLUSION

The infestation of *S. frugiperda* was higher at an elevation of 30 masl compared to locations at 600 masl and 1000 masl. Scoring leaf damage caused by *S. frugiperda* infestation at 30 masl: 2,73–4,86, at 600 masl: 2,73–3,55, and at 1000 m masl: 2,4–3,37.

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AUTHORS' CONTRIBUTIONS

MZ and SS considered and planned the experiment. SG collecting data on the plant damage caused by *Spodoptera frugiperda*. MZ performing analysis and interpreting the plant damage data. SG prepared the manuscript. The authors provided responses and comments on the research flow, data analysis, and interpretation as well as the shape of the manuscript. All the authors have read and approved the final manuscript.

COMPETING INTEREST

I declare no competing interests regarding this publication.

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