Eco-Enzyme Application Reduces *Spodoptera frugiperda* (J.E. Smith) Infestation on Sweet corn (*Zea mays* saccharata Sturtev.): Insights into Sustainable Pest Management

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Abstract. *Spodoptera frugiperda* (J.E. Smith) (fall armyworm) is a major pest of *Zea mays* saccharata Sturtev. that causes severe leaf damage during the vegetative stage. Continuous use of chemical pesticides leads to resistance and environmental pollution, necessitating the exploration of eco-friendly alternatives. Eco-enzyme, a bio-based liquid produced from the fermentation of organic waste, contains organic acids and enzymes that may enhance plant resistance and suppress pest activity. This study aimed to evaluate the effect of eco-enzyme application on *S. frugiperda* infestation, attack intensity, and population during the vegetative phase of maize. The experiment was conducted from July to September 2025 at the Teaching and Research Farm, Faculty of Agriculture, Jambi University, using two treatments: without and with eco-enzyme application. Observations were made from 2 to 6 weeks after planting (WAP), and data were analyzed using an independent t-test (α = 0.05). The results showed that eco-enzyme treatment significantly reduced the infestation percentage, attack intensity, and pest population compared to those control. At 6 WAP, infestation reached 100% in the control and 92% with eco-enzyme, with attack intensity values of 43.56% and 35.56%, respectively. These results suggest that eco-enzyme effectively suppresses *S. frugiperda* and can be used in integrated pest management.

Keywords: *Eco-enzyme; Integrated pest management; Spodoptera frugiperda; Sustainable agriculture; Zea mays.*

1. Introduction

Zea mays is a staple crop of global importance, serving as a critical source of food, feed, and raw material for industrial processing. However, its production is increasingly threatened by pest infestations, particularly *S. frugiperda* [1], [2]. Its high reproductive potential, migratory ability, and capacity to develop resistance against synthetic insecticides make it a serious pest under current agricultural practices [3], [4].

During corn plant vegetative stage, *S. frugiperda* larvae feed voraciously on Sweet corn leaf, reating characteristic window-like lesions that can severely reduce photosynthetic capacity. Under heavy infestations, yield losses may exceed 70% if no control measures are applied [5]. The pest's aggressive feeding behavior and overlapping generations cause continuous pressure on Sweet corn throughout its grouth cycle, posing significant economic and ecological challenges. In Indonesia and other Southeast Asian countries, the spread of *S.*

frugiperda has forced farmers to rely heavily on chemical insecticides, often applied indiscriminately and at high frequencies [6]. Although these chemicals provide short-term relief, their long-term use has led to the emergence of resistant *S. frugiperda* populations, decreased natural enemy abundance, and environmental contamination [7]. Consequently, there is an urgent need to develop environmentally benign and sustainable pest management strategies.

One promising alternative is the use of bio-based pest control agents, including microbial pesticides, plant extracts, and eco-enzyme formulations derived from organic waste. Eco-enzyme, a liquid product of fermenting fruit or vegetable waste with sugar and water, has gained attention for its multifunctional agricultural applications, such as soil conditioner, growth stimulant, and pest suppressant [8], [9]. The fermentation process produces a complex mixture of organic acids, enzymes, alcohols, and volatile compounds, which can influence plant physiological processes and pest behavior [10], [11]. Recent studies suggest that eco-enzyme contains bioactive compounds with antifeedant, repellent, or toxic properties that can interfere with insect growth and feeding [12]. Additionally, the acidic nature and enzymatic components of eco-enzyme may enhance plant defense mechanisms by promoting systemic resistance and altering leaf surface chemistry, thus reducing pest preference and oviposition [9], [10].

In the context of sweet corn cultivation, eco-enzyme represents a cost-effective and eco-friendly solution that aligns with the principles of Integrated Pest Management (IPM) and sustainable agriculture. Unlike synthetic insecticides, eco-enzyme does not leave toxic residues and can be easily prepared by farmers using locally available materials, making it suitable for community-based pest management programs [9], [13]. However, despite its potential, empirical data on the efficacy of eco-enzyme against *S. frugiperda*, particularly under field conditions, remain scarce. Previous tudies have focused on the chemical characterization and microbial composition of eco-enzyme, rather than its practical impact on pest infestation and population dynamics.

Understanding the interaction between eco-enzyme application and *S. frugiperda* population dynamics is essential for validating its potential as a bio-rational control method. The vegetative stage of maize, which coincides with the peak period of *S. frugiperda* activity, provides an ideal window to evaluate the effectiveness of such interventions. The presence of young, tender leaves at this stage makes the crop particularly vulnerable, while the pest's oviposition behavior is known to be influenced by plant volatiles emitted during early growth [14], [15]. Hence, assessing eco-enzyme's role in modifying these dynamics offers valuable insights into its mode of action and practical relevance.

This study was conducted to evaluate the effect of eco-enzyme application on *S. frugiperda* infestation, attack intensity, and population during the vegetative growth phase of maize. The experiment compared two treatments — with and without eco-enzyme application — over six weeks after planting (2–6 WAP). Results demonstrated that eco-enzyme significantly reduced pest infestation and damage intensity compared to the untreated control, indicating its potential as a natural pest suppressor. These findings reinforce the hypothesis that eco-enzyme can act not only as a deterrent but also as a modifier of plant–pest interactions through ecological and biochemical pathways.

The exploration of eco-enzyme as a pest management tool contributes to the broader agenda of sustainable agricultural innovation. By utilizing organic waste as raw material, eco-enzyme supports circular bioeconomy principles, reducing waste while providing an environmentally sound alternative to chemical pesticides. Integrating eco-enzyme into pest management frameworks could reduce farmers' dependency on synthetic chemicals, promote ecological balance, and enhance resilience in maize-based agroecosystems.

2. Research Methods

The study was conducted to evaluate the effect of eco-enzyme application on the infestation rate, attack intensity, and population dynamics of *S. frugiperda* on Sweet corn(Zea mays L.) during the vegetative stage. The experiment took place from July to September 2025 at the Teaching and Research Farm, Faculty of Agriculture, Universitas Jambi, Indonesia (1.6164404oS, 103.521′E), which has a tropical climate characterized by an average temperature of 28–32°C and relative humidity ranging between 75–85%. The experimental field had been previously cultivated with Sweet corn and maintained under conventional agronomic practices, ensuring uniform soil fertility and structure before planting.

The experimental design consisted of two cropping pattern treatments to assess the effectiveness of eco-enzym application in reducing *S. frugiperda* infestation. The cropping pattern treatments consisted of sweet corn plants without eco-enzyme application as the control (A), and sweet corn plants with eco-enzyme application. Each treatment was established in a 20 m × 10 m plot, with a 10 m buffer zone between plots to prevent treatment interference and minimize insect movement. Sweet corn was planted by dibbling at a spacing of 40 cm × 75 cm. The preparation of eco-enzyme followed the method described by Yong [16]. The process requires three main ingredients: brown sugar, fresh fruit peels or vegetable residues, and water, in a ratio of 1:3:10. A 15 L plastic container was used for fermentation.

First, 1,000 g of brown sugar was dissolved in 10 L of water inside the container. Then, various fresh fruit peels and plant materials were added, including 300 g pineapple peel, 300 g banana peel, 300 g papaya peel, 300 g lemongrass, 400 g noni fruit, 300 g turmeric, 150 g watermelon rind, 150 g pandan leaves, 300 g orange peel, 200 g soursop leaves, 250 g papaya leaves, and 100 g moringa leaves. The mixture was stirred thoroughly to ensure uniform distribution of the materials.

The container was then tightly sealed and secured with tape around the lid to prevent air leakage. It was placed in a clean, shaded area with good air circulation. The fermentation process lasted for three months. The resulting eco-enzyme solution had a fresh aroma and an acidic pH of 3–4. After fermentation, the mixture was filtered to separate the solid residues from the liquid eco-enzyme. The filtrate was then stored in 1.5 L plastic bottles, tightly sealed, and kept for further use.

Eco-enzyme was applied at a concentration of 0.3% (v/v) and sprayed uniformly onto the foliage of maize plants using a hand-held sprayer to ensure even coverage of the leaf surfaces. Applications were conducted once a week during the experimental period, preferably in the morning to optimize absorption and effectiveness.

A systematic sampling method was applied to select observation units within each treatment plot. In both treatments, five sample plots were established, each comprising 25 corn plants. These plants served as the primary units for recording all observational parameters related to *S. frugiperda* incidence and crop productivity. Observations were conducted at regular intervals during the crop growth stages to ensure accurate and consistent data collection. Three parameters were measured: infestation percentage, infestation intensity, and larval population density. Observations were conducted weekly from 2 to 6 WAP. Infestation percentage was determined by calculating the proportion of Sweet cornplants showing visible symptoms of *S. frugiperda* damage, using the formula:

$$\text{Infestation percentage} = \frac{\text{Number of infested plants}}{\text{Total number of observed plants}} \times 100$$

Infestation intensity was assessed visually using a standard 0–9 scale modified from Davis (17), where 0 = no damage and 9 = severe damage with whorl destruction. The mean intensity per treatment was expressed as a percentage relative to the maximum possible score.

Larval population density was determined by counting the number of larvae per plant from five randomly selected plants per plot. Observations were conducted in the morning (07:00–09:00) to minimize larval movement bias.

All collected data were subjected to normality and homogeneity tests prior to analysis. An independent t-test (α = 0.05) was performed using IBM SPSS Statistics 26 to compare means between treatments (eco-enzyme vs. control) for each observation period. Mean separation was based on significance levels ($p < 0.05$), and significant differences were indicated by different letters in tables and figures. To visualize trends, infestation percentage, intensity, and larval population were plotted over time (2–6 WAP). These analyses aimed to determine whether eco-enzyme application significantly influenced pest suppression across observation periods.

3. Results and Discussion

3.1 Infestation of S. frugiperda.

Infestation rates increased with plant age in both treatments. The control group consistently showed higher infestation levels than the eco- enzyme treatment across all observation periods. Significant differences (paired t- test, α = 0.05) were observed at 2–4 WAP, indicating that eco- enzyme effectively reduced infestation. At 5 WAP, the difference was not significant, while at 6 WAP, the eco- enzyme treatment remained slightly lower (92%) than the control (100%) (Table 1).

Table 1. Percentage of *S. frugiperda* Infestation (mean ± SD)

Treatments	2 WAP	3 WAP	4 WAP	5 WAP	6 WAP
No eco-enzyme aplication	71,2±13,39 a	73,6±9,21 a	83,2±9,96 a	89,6±7,80 a	100±0,00 a
Eco-enzyme aplication	36,8±5,22 b	52±6,32 b	64±4,90 b	81,6±6,07 a	92±7,48 b

Note: Numbers followed by different letters in the same column are significantly different according to a paired t-test (α = 0.05).

Table 1 presents the percentage of Spodoptera frugiperda infestation on Sweet cornplants with and without the application of eco-enzyme at different observation times (2–6 weeks after planting, WAP). In general, the infestation percentage increased as the plants grew older in both treatments. The treatment without eco-enzyme consistently showed a higher level of infestation compared to the eco-enzyme treatment at almost all observation periods. Significant differences (indicated by different letters) were observed at 2–4 WAP, where the application of eco-enzyme effectively reduced the infestation rate. At 5 WAP, the difference was not significant, while at 6 WAP the infestation remained slightly lower in the eco-enzyme treatment (92%) compared to the control (100%).

Table 2. *S. frugiperda* infestation intensity

Treatments	2 WAP	3 WAP	4 WAP	5 WAP	6 WAP
No eco-enzyme aplication	8,89±0,00 a	25,33±1,22 a	35,56±2,22 a	38,22±1,86 a	43,56±1,99 a
Eco-enzyme aplication	5,33±1,22 b	14,67±1,22 b	23,56±2,53 b	31,56±1,86 b	35,56±3,51 b

Note: Numbers followed by different letters in the same column are significantly different according to a paired t-test (α = 0.05).

The intensity of *S. frugiperda* infestation on sweet corn plants under different treatments is presented in Table 2. The infestation intensity increased gradually from 2 to 6 weeks after planting (WAP) in both treatments. However, the intensity was consistently lower in plots treated with eco-enzyme compared to those without application throughout the observation period. At 2 WAP, the infestation intensity in the eco-enzyme treatment (5.33 ± 1.22%) was significantly lower than in the control (8.89 ± 0.00%). This trend continued through subsequent weeks, with infestation levels reaching 35.56 ± 3.51% in the eco-enzyme treatment and 43.56 ± 1.99% in the control at 6 WAP. Statistical analysis indicated significant differences between treatments at all observation times (paired t-test, α = 0.05), as shown by different letters in each column.

Table 3. *S. frugiperda* population

Treatments	2 WAP	3 WAP	4 WAP	5 WAP	6 WAP
No eco-enzyme aplication	8,2±1,92 a	5,2±2,59 a	11,4±2,30 a	11,8±2,39 a	5,2±1,91 a
Eco-enzyme aplication	4,2±1,3 b	3±1,41 b	5,4±1,14 b	5,6±2,07 b	2±0,82 b

Note: Numbers followed by different letters in the same column are significantly different according to a paired t-test (α = 0.05).

The population of *S. frugiperda* larvae observed under different treatments is presented in Table 3. The population dynamics varied across the observation period, with notable differences between the control and eco-enzyme treatments. At 2 WAP, the mean larval population in the control plots (8.2 ± 1.92) was significantly higher than that in plots treated with eco-enzyme (4.2 ± 1.30). A similar pattern was observed at all subsequent observation periods, indicating that eco-enzyme application suppressed the population of *S. frugiperda* throughout the growing period. The larval population in the control plots reached its peak at 5 WAP (11.8 ± 2.39), whereas the highest population in the eco-enzyme treatment occurred at 5 WAP as well but with a considerably lower mean (5.6 ± 2.07). Statistical analysis revealed that the differences between treatments at each observation time were significant (paired t-test, α = 0.05), as indicated by different letters in each column.

The present study evaluated the effect of eco-enzyme application on Spodoptera frugiperda infestation, infestation intensity, and larval population on sweet corn. The data from Tables 1–3 consistently show that eco-enzyme application suppressed *S. frugiperda* incidence and severity throughout the observation period. The percentage of infested plants increased as the crop developed, from 2 to 6 weeks after planting (WAP), in both treatments. However, plots without eco-enzyme consistently had higher infestation levels than those with eco-enzyme. Significant differences were observed at 2–4 WAP, where eco-enzyme significantly reduced *S. frugiperda* infestation Although at 5 WAP the difference was not significant, infestation at 6 WAP remained slightly lower in the eco-enzyme treatment (92 %) compared with the control (100 %) (Table 1). This pattern indicates that eco-enzyme effectively delayed the onset and progression of infestation, providing early protection to plants during their most vulnerable vegetative stages. Early suppression is critical because *S. frugiperda* larvae cause the most severe damage during the early whorl stage of maize [18].

In the untreated plots the infestation intensity increased steadily from 8.89 ± 0.00 % at 2 weeks after planting (WAP) to 43.56 ± 1.99 % at 6 WAP. In contrast, the eco-enzyme plots exhibited a lower increase from 5.33 ± 1.22 % at 2 WAP to 35.56 ± 3.51 % at 6 WAP (Table 2). Similarly, larval population counts were consistently lower in the eco-enzyme treatment—e.g., 4.2 ± 1.30 larvae at 2 WAP compared to 8.2 ± 1.92 in the control (Table 3). Significant differences between treatments were observed at all sampling times. These results indicate that eco-enzyme application suppressed early establishment and development of *S. frugiperda*, thereby mitigating damage pressure during the critical vegetative growth stage of sweet corn.

The upward trend in infestation intensity and larval population over time in both treatments is consistent with known pest ecology: as plants mature they provide greater biomass, nutritional resources, and microhabitats favorable for herbivore development [3]. *S. frugiperda* is highly polyphagous and exhibits strong capacity for population build-up under favourable conditions. Its invasive behavior, wide host-range, and capacity for rapid reproduction emphasise the need for effective suppression early in the crop cycle [3]. The fact that the eco-enzyme treatment maintained a lower trajectory than that of the untreated control, suggesting that it interferes with one or more critical stages of the pest lifecycle—potentially reducing oviposition, larval survival, feeding damage or larval development rates.

Although the precise mode of action of the eco-enzyme in this context is not defined, literature on eco-enzymes suggests several plausible mechanisms. Eco-enzymes are fermentation-derived liquids from fruit or vegetable waste that contain organic acids (e.g., acetic acid), enzymes (lipases, amylases, proteases) and microbial metabolites and they have been documented for roles in disinfection, bio-fertilisation, soil improvement and, in some cases, pest or insect deterrence [19]. Although research on eco-enzyme efficacy specifically against *S. frugiperda* is scant, the present results demonstrate potential for use as a bio-suppression tool. Additionally, chemical characterisation studies show eco-enzymes contain biologically active compounds that might reduce pest feeding activity or survival [20].

From an integrated pest management (IPM) perspective, the documented reduction of infestation and larval numbers supports the inclusion of eco-enzyme as a component of sustainable pest control strategies for *S. frugiperda*. Conventional control of this pest is increasingly challenging due to its development of insecticide resistance, rapid migration, and high reproduction rate [21]. IPM frameworks emphasise low-input, environmentally friendly tactics—including cultural controls, biological agents (parasitoids, viruses), resistant cultivars, and minimal chemical use [21]. The eco-enzyme treatment aligns with these goals: it is derived from organic waste, may support soil fertility and plant health (thus indirectly enhancing host-plant resistance), and appears to reduce direct pest pressure. In practice, the use of eco-enzyme may delay the need for insecticide use, reduce overall damage, and contribute to improved sustainability of sweet corn production.

However, several limitations should be acknowledged. Although differences between treatments were significant from 2–4 WAP, they became non-significant by 5 WAP and diminished further by 6 WAP, indicating that the efficacy of eco-enzyme application may decline under increasing pest pressure and crop canopy development. In addition, the study was conducted within a single growing season and under specific field conditions, which may limit the generalizability of the findings across different agroecological environments. Furthermore, the underlying mechanisms of eco-enzyme action were not directly investigated; thus, the observed reduction in infestation may be associated with effects on oviposition, larval survival, feeding behaviour, or microclimatic conditions, but these mechanisms remain to be experimentally verified. Accordingly, eco-enzyme application should be considered primarily as a preventive or early-stage intervention rather than a standalone solution under high-infestation conditions.

Second, mechanistic studies are lacking in this particular system. Future work should examine how eco-enzyme treatments affect feeding behaviour, larval mortality, developmental duration, oviposition preference, and possible enhancement of host-plant resistance (e.g., induced plant defence responses). For example, Gao et al [22] demonstrated that *S. frugiperda* larvae's salivary secretions suppress maize defence induction, highlighting how host–pest interactions occur at biochemical levels; evaluating whether eco-enzyme influences plant defence pathways could provide further insight. Third, yield outcomes and economic analyses are required to establish farmer-relevant benefits: reduced infestation and population are promising, but ultimately the key metric is improved yield or reduced crop loss. Cost-benefit analysis of eco-enzyme preparation, application frequency, labour and results relative to conventional insecticides would strengthen recommendations for adoption.

While the eco-enzyme treatment may contribute to pest suppression, it should ideally be integrated with other IPM components. For example, intercropping, push-pull systems, parasitoids and microbial biocontrol agents have been shown to provide effective suppression of *S. frugiperda* [21]. Combining eco-enzyme with these Approaches may achieve additive or synergistic effects. Additionally, environmental factors (temperature, humidity, rainfall, crop density, nutrient status) may modulate efficacy and deserve monitoring.

Finally, practical implementation aspects must be considered: dosage, timing, method of application (foliar spray, soil drench, seed treatment), concentration and frequency of eco-enzyme application need optimisation for different cropping systems and agro-ecological zones. Studies on eco-enzyme formulation from kitchen or agricultural waste show that substrate type, fermentation time, and dilution ratio affect active compound concentrations and pH/acidity [23]. Ensuring quality control and standardisation will be important for consistent performance.

4. Conclusions

The study provides evidence that eco-enzyme application can reduce infestation intensity and larval population of *S. frugiperda* on sweet corn, especially during early growth stages. The findings support the inclusion of eco-enzyme within sustainable pest management programs. To maximise benefits, we recommend its use as part of an integrated strategy, applied early in the crop cycle, and combined with other non-chemical controls. Further research should clarify its mechanism of action, refine application protocols, measure yield responses and evaluate cost-effectiveness under farmer conditions.

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