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The Resistance of *Spodoptera frugiperda* to Carbamate-Class Insecticides in Serang Regency, Indonesia

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Abstract

Spodoptera frugiperda is a pest native to tropical and subtropical America. This pest is invasive and has spread to other parts of the world. Farmers use synthetic chemical pesticides in pest control because they are easily available and have a rapid population suppression rate. Carbamates are a group of insecticide compounds that have the potential to disrupt the central nervous system. Resistance is a negative impact of irresponsible insecticide use. This study aims to determine the level of resistance of Spodoptera frugiperda to synthetic carbamate insecticides. The study used a completely randomized design (CRD) consisting of two factors. The first factor was the insecticide treatment, including control (no insecticide), carbaryl, methomyl, and carbofuran. The second factor was the concentration levels of 5%, 20%, 50%, 75%, and 95%, with three replications for each treatment. Data were analyzed using analysis of variance (ANOVA), probit analysis (SPSS software), and Duncan's Multiple Range Test (DMRT) as a post hoc test. The results indicated that field populations of Spodoptera frugiperda in Serang Regency, Indonesia, were suspected of having developed resistance to carbaryl. Differences in insecticide performance among the tested carbamate active ingredients highlight the importance of selecting effective insecticides for S. frugiperda management. Based on the LT and LC values, methomyl exhibited the highest toxicity among the tested carbamate insecticides and may be considered a potential option for managing *S. frugiperda*, although further field validation is recommended. This study also documented changes in larval body morphology, coloration, and odor following exposure to the tested insecticides.

Keywords: Carbaryl, LC_{50}, LT_{50}, Maize, Methomyl

1. Introduction

One of the major food crops that plays a crucial role in supporting Indonesia's economy is maize (*Zea mays* L.). Following rice, maize serves as an important source of protein and carbohydrates. In addition, maize is widely utilized as animal feed. According to data from the Serang City Statistics Agency, maize production in Serang City declined from 435 tons in 2019 to 93 tons in 2020.The presence of insect pests represents one of the major challenges in crop production management. According to Sayuthi *et al*. (2020), the occurrence of crop pest infestations poses a significant threat to agricultural production by reducing yield quantity and quality, thereby leading to considerable economic losses.

Spodoptera frugiperda is one of the most destructive insect pests of maize, causing severe damage by feeding on leaves, whorls, and reproductive tissues. Known for its high feeding capacity, *S. frugiperda* larvae frequently burrow into plant tissues to feed (Maharani *et al*., 2025). Under heavy infestations, yield losses can be substantial, resulting in significant economic impacts on maize production. Lestari *et al*. (2020), reported that maize crop damage caused by *S. frugiperda* infestation in Lampung Province reached 70%. The pest's high reproductive capacity, wide host range, and strong dispersal ability make effective management particularly challenging.

The fall armyworm, *S. frugiperda*, is a pest native to tropical and subtropical regions of America. Since its first detection in Africa in 2016, the larvae of *S. frugiperda* attack the plant growing point, resulting in inhibited new leaf development and ultimately causing maize plant mortality. Following leaf damage, *S. frugiperda* larvae leave only the leaf veins and stems of the plant (Wulansari *et al*., 2021). Maize plants are susceptible to infestation by

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S. frugiperda larvae throughout the vegetative and generative growth stages. The final instar larvae possess the ability to damage various parts of the plant. Several countries have reported the spread of this pest, including Africa, India, Sri Lanka, Thailand, Myanmar, China, Indonesia, and Malaysia. This pest was first detected in Indonesia in 2019 in maize plantations located in West Pasaman, West Sumatra. Its distribution in Indonesia has been reported in several regions, including Bandung, Garut, Sumedang (West Java), as well as Central Lampung and East Lampung (Sumaryati *et al*., 2023).

The application of synthetic insecticides remains the primary approach adopted by farmers for managing *S. frugiperda* in maize crops. Chemical control methods are widely favored due to their practicality, ease of access, and effectiveness in rapidly suppressing pest populations. Since the 1950s, Indonesia has relied on various chemical pesticides for agricultural pest management (Alfiansyah *et al*., 2023). One of the synthetic insecticides used belongs to the carbamate class.

According to Ananto *et al*. (2017), carbamates are a group of insecticides that have the potential to disrupt the central nervous system. Acetylcholinesterase (AChE) enzymes are inhibited by carbamate compounds through a carbamylation process. The inhibition of this enzyme results in an accumulation of acetylcholine, which binds to muscarinic and nicotinic receptors in the central and peripheral nervous systems. This condition leads to the development of toxic symptoms that affect various parts of the body. Repeated use of insecticides in pest management can lead to the development of pest populations with the ability to survive insecticide exposure. This condition may result in changes in pest sensitivity to the active ingredients used, thereby reducing the effectiveness of pest control. Akeme *et al*. (2021), reported that *S. frugiperda* populations in the United States have developed resistance to carbamate insecticides. Susanto *et al*. (2021), demonstrated that emamectin benzoate, chlorfenapyr, phoxim, methomyl, and indoxacarb were the most effective insecticides, producing mortality rates exceeding 80% against *S. frugiperda* under laboratory, greenhouse, and field conditions.

Therefore, this study aims to determine the level of resistance of *S. frugiperda* to synthetic carbamate insecticides. This study is also expected to provide information regarding insecticides that still demonstrate optimal control potential against *S. frugiperda*. Furthermore, the findings may serve as a source of information to support integrated pest management strategies, particularly in the selection and appropriate use of insecticides.

2. Material and Methods

2.1. Location and Time of Study

This study was conducted from November 2025 to March 2026 at the Basic Sciences and Plant Protection Laboratory, 3rd Floor, Faculty of Agriculture, Sultan Ageng Tirtayasa University. The laboratory is located at 6°11′27.5″ S, 106°07′28″ E, with an elevation of approximately 75–85 m above sea level (a.s.l.).

2.2. Materials and Equipment

The equipment used in this study included a 250-mL beaker glass, 50-mL plastic cups, insect rearing cages, permanent markers, an analytical balance, latex gloves, a 1000-µL micropipette, blue pipette tips, a 50-megapixel camera, paintbrushes, a spatula, scissors, forceps, a pestle, a mortar, a 50-mL graduated cylinder, and stationery. The materials used in this study consisted of fall armyworm (*S. frugiperda*) larvae, distilled water, alcohol, maize ears, maize leaves, honey, cotton, tissue paper, sewing thread, carbamate-based insecticides, and water.

2.3. Rearing of the Test Insects

Samples of *S. frugiperda* were collected through direct field observations in maize cultivation areas located on Jalan Raya Petir, Cimaung, Cikeusal District, Serang Regency, Banten Province, Indonesia. The insects were carefully collected using a paintbrush to prevent physical damage and ensure specimen integrity. The insect pest was reared in plastic cups until the third generation. Each plastic cup contained a single larva due to its cannibalistic behavior. Rearing was conducted under a temperature range of 25°C–28°C. Larvae of instar 1–3 were fed leaf material, whereas instar 4–5 were provided with maize cobs as food. The adults emerging from pupae were supplied with honey solution absorbed on cotton, which was suspended inside the rearing cage using sewing thread.

2.4. Test Insecticides

Three insecticides were used in this study, namely Sevin 85 SP (Soluble Powder), which contains carbaryl as the active ingredient; Dangke 40 WP (Wettable Powder), which contains methomyl as the active ingredient; and Furadan 3 GR (Granular), which contains carbofuran as the active ingredient. Sevin was manufactured by PT Agricon, Dangke by PT Dharma Guna Wibawa (DGW), and Furadan by PT Bina Guna Kimia (FMC). The determination of treatment concentrations was based on the recommended application rates stated on the product labels. These rates were used as reference values to establish the range of experimental concentrations under laboratory conditions. The insecticide solution was prepared by direct dilution according to the specified treatment concentration.

2.5. Experimental Procedure

The larvae used in this study consisted of a mixture of larvae at instars 4 and 5. The larvae were fed with maize kernels as the diet. Feeding was conducted by immersing maize kernels in the insecticide solution for 10 seconds, followed by air-drying for 5 minutes before exposure. Larvae were continuously exposed to treated food from the initial application until mortality occurred or until the end of the observation period, which lasted for 7 days. Insecticide-treated maize kernels were provided once daily at a rate of four kernels per larva. Larval mortality was assessed based on the absence of movement or response to gentle prodding with a fine brush. Individuals that survived until the end of the observation period and successfully developed into pupae or adults were recorded as surviving individuals.

2.6. Experimental Design

The experimental design used in this study was a Completely Randomized Design (CRD) arranged in a factorial scheme consisting of two factors. The first factor was insecticide type, comprising carbamate-based active ingredients, namely carbaryl, methomyl, carbofuran, and a control treatment (without insecticide application). The second factor was insecticide concentration, which consisted of five levels 5%, 20%, 50%, 75%, and 95% for each insecticide. A total of 20 treatment combinations were obtained from the interaction of the two factors. Each treatment combination was replicated three times, resulting in 60 experimental units. Each replicate consisted of six larvae, yielding a total of 360 larvae required for the entire experiment.

The control treatment contained no insecticide and consisted only of distilled water. However, it was included corresponding to each tested concentration level (5%, 20%, 50%, 75%, and 95%) in the experimental setup. Each insecticide concentration treatment was paired with a corresponding control treatment to correct for natural mortality in the tested insects and to adjust the observed mortality caused by insecticide exposure using Abbott's formula.

2.7. Data Analysis

The data obtained in this study were analyzed using analysis of variance (ANOVA) and probit analysis. Observational data were subjected to analysis of variance (F-test) at a 5% significance level. When the analysis of variance indicated a significant or highly significant effect, Duncan's Multiple Range Test (DMRT) was performed as a post hoc test to compare treatment means.

Probit analysis was conducted using IBM SPSS software to estimate the Lethal Concentration 50 (LC_{50}), Lethal Time 50 (LT_{50}), Lethal Concentration 90 (LC_{90}), and Lethal Time 90 (LT_{90}) values based on mortality data of *S. frugiperda*. Mortality percentages were calculated using Abbott's formula. The following equation was used to determine uncorrected (absolute) mortality without control correction (Rustama *et al.*, 2008; Rosandy *et al.*, 2024). The overall research flow diagram is presented in Figure 1.

$$\textbf{Absolute Mortality (\%)} = \frac{\mathbf{n}}{\mathbf{N}} \times \mathbf{100}$$

Notation:
n = number of dead individuals
N = total number of individuals tested

If the mortality of the test insects in the control treatment is greater than 0% but less than 20%, mortality correction is performed using Abbott's formula (Rosandy *et al.*, 2024), as follows:

$$\textbf{Corrected Mortality (\%)} = \frac{\mathbf{Mt-Mc}}{\mathbf{100-Mc}} \times \mathbf{100}$$

Notation:
Mt = mortality in the insecticide treatment (%)
Mc = mortality in the control treatment (%)

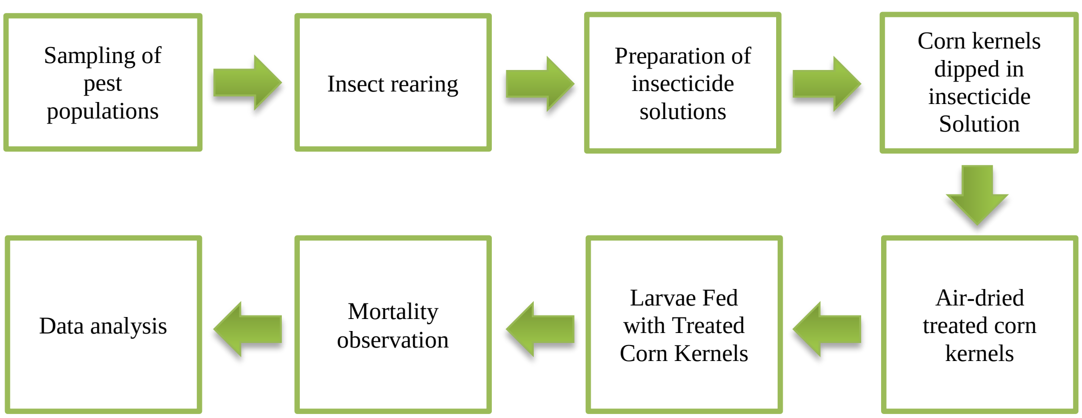

Figure 1. Research flow diagram

3. Results and Discussion

After the application of the three carbamate insecticides, differences in mortality rates were observed among the treatments. Mortality percentages were used to describe the effectiveness of each insecticide in controlling the field population of *S. frugiperda*. The mortality percentages were calculated using Abbott's formula, as presented in the following table.

Based on the results of calculations using Abbott's formula presented in Table 1, the insecticide treatments showed differences in corrected mortality. The larval mortality rate following the application of various active ingredients and concentrations increased across all treatments. The observed increase in larval mortality during the observation period indicates that insecticide efficacy is time-dependent. According to Leong *et al*. (2020), that prolonged exposure can lead to the complete elimination of insects, as the test insects experience greater contact with the insecticide over time.

Table 1. Corrected mortality of *Spodoptera frugiperda* exposed to different carbamate insecticides and concentrations

Treatment	Days Post-Application						
	1	2	3	4	5	6	7
	…%…						
Carbaryl1	0 ± 0,00 c	16,66 ± 16,67 c	16,66 ± 16,67 c	16,66 ± 16,67 c	37,50 ± 24,22 c	56,25 ± 20,03 b	93,75 ± 5,56 a
Carbaryl2	5,55 ± 5,55 c	22,22 ± 22,22 c	27,77 ± 27,78 c	33,33 ± 25,46 c	56,25 ± 22,22 c	87,49 ± 5,56 b	93,75 ± 5,56 a
Carbaryl3	5,55 ± 5,55 c	22,22 ± 22,22 c	22,22 ± 22,22 c	38,88 ± 24,22 c	70,59 ± 5,56 c	76,46 ± 5,56 b	100,00 ± 0,00 a
Carbaryl4	0 ± 0,00 c	0 ± 0,00 c	0 ± 0,00 c	5,55 ± 5,55 c	47,06 ± 25,46 c	58,82 ± 20,03 b	100,00 ± 0,00 a
Carbaryl5	5,55 ± 5,55 c	22,22 ± 22,22 c	22,22 ± 22,22 c	38,88 ± 24,22 c	52,94 ± 20,03 c	70,59 ± 11,11 b	88,23 ± 5,56 a
Methomyl1	72,22 ± 14,70 a	72,22 ± 5,56 a	100,00 ± 0,00 a	100,00 ± 0,00 a	100,00 ±0,00 a	100,00 ±0,00 a	100,00 ± 0,00 a
Methomyl2	55,55 ± 5,55 a	55,55 ± 5,56 a	100,00 ± 0,00 a	100,00 ± 0,00 a	100,00 ± 0,00 a	100,00 ± 0,00 a	100,00 ± 0,00 a
Methomyl3	83,33 ± 16,67 a	100,00 ± 0,00 a	100,00 ± 0,00 a	100,00 ± 0,00 a	100,00 ± 0,00 a	100,00 ± 0,00 a	100,00 ± 0,00 a
Methomyl4	61,11 ± 14,70 a	61,11 ± 5,56 a	88,88 ± 5,56 a	88,88 ± 5,56 a	88,23 ± 5,56 a	94,11 ± 5,56 a	94,11 ± 5,56 a
Methomyl5	72,22 ± 20,03 a	100,00 ± 0,00 a	100,00 ± 0,00 a	100,00 ± 0,00 a	100,00 ± 0,00 a	100,00 ± 0,00 a	100,00 ± 0,00 a
Carbofuran1	11,11 ± 11,11 b	22,22 ± 22,22 b	22,22 ± 22,22 b	22,22 ± 14,70 b	56,25 ± 5,55 b	74,99 ± 11,11 b	100,00 ± 0,00 a
Carbofuran2	5,55 ± 5,55 b	44,44 ± 20,03 b	44,44 ± 20,03 b	44,44 ± 20,03 b	62,49 ± 25,46 b	81,25 ± 9,62 b	100,00 ± 0,00 a
Carbofuran3	16,66 ± 9,62 b	66,66 ± 9,62 b	66,66 ± 9,62 b	77,77 ± 5,56 b	82,35 ± 0,00 b	88,23 ± 5,56 b	100,00 ± 0,00 a
Carbofuran4	16,66 ± 0,00 b	88,88 ± 11,11 b	88,88 ± 11,11 b	88,88 ± 11 11 b	88,23 ± 11,11 b	88,23 ± 11,11 b	100,00 ± 0,00 a
Carbofuran5	44,44 ± 29,40 b	77,77 ± 22,22 b	77,77 ± 22,22 b	77,77 ± 22,22 b	76,46 ± 22,22 b	82,35 ± 16,67 b	100,00 ± 0,00 a

Note: Mortality values followed by the same letters are not significantly different according to DMRT at the 5% significance level.

The highest mortality was recorded in the methomyl treatment, whereas the lowest mortality was observed in the carbaryl treatment. These findings indicate that the efficacy of each active ingredient in controlling the pest differs. Furthermore, the type of insecticide used has a significant influence on its effectiveness in inducing pest mortality. According to Maurer *et al*. (2024), that the efficacy of the tested insecticides in causing mortality of agricultural pests is associated with their mode of action, target insect sensitivity, exposure and contact with the insect, residual activity, formulation type, and active ingredient concentration.

In the methomyl treatment, larval mortality was observed one day after application, with a higher percentage of mortality compared to the other two insecticides. This finding indicates that the insecticide containing methomyl as the active ingredient exhibited a faster toxic effect on *S. frugiperda* mortality than insecticides containing carbaryl and carbofuran. This result is consistent with Filho *et al*. (2026), who reported that neurotoxic insecticides, such as carbamates (methomyl), have been identified as promising candidates for toxic bait formulations due to their rapid mode of action.

Increasing the insecticide concentration did not consistently lead to a significant increase in mortality. This suggests that the tested population showed differential sensitivity to the active ingredients. According to the DMRT results presented in Table 1, variations in insecticide type had a greater influence on pest control efficacy than increases in application concentration.

The lack of a significant effect of concentration on mortality suggests that the increase in insecticide concentration within the tested range did not result in a significant increase in larval mortality. High concentrations may induce feeding deterrence, leading to reduced feeding activity and decreased food consumption by the insects (Manikome & Handayani, 2019; Ramadhan & Nurhidayah, 2022). The decrease in larval feeding activity on insecticide-treated feed may be related to the repellent effects of the insecticide compounds, including the bitter taste and pungent odor, which may affect the larvae's acceptance of the treated feed (Azwana *et al*., 2019; Mursyidin *et al*., 2026). These findings indicate that selecting the right type of insecticide is the main determinant of control effectiveness, not simply increasing the insecticide concentration (Table 1).

The mortality observed in the control treatment is likely related to the biological characteristics of the insect population used in this study. Field-collected *S. frugiperda* populations have been exposed to a variety of environmental conditions, which may result in variations in adaptive capacity and survival among individuals.

Population susceptibility to insecticides may remain variable even when cultured in the laboratory. Previous studies have reported that *S. frugiperda* exhibits high genetic diversity. Genetic diversity represents the level of biodiversity, which refers to the degree of genetic variation within a species. Genetic variation in *S. frugiperda* is thought to be influenced by its wide geographic distribution (Belay *et al*., 2012; Lestari *et al*., 2020).

Differences in feeding conditions provided in laboratory conditions compared to natural food sources in the field can affect nutrient intake, growth, and survival of larvae. Suroto *et al*. (2021), reported that differences in the nutritional composition of larval diets influenced larval survival. Larvae fed purslane had a mean survival time of 2 days, whereas those fed maize survived for an average of 5 days and those fed caisim survived for an average of 6 days. In this study, larvae were reared using peeled corn kernels obtained from fresh corncobs as a natural food source. However, fresh corncobs used as larval feed can experience quality degradation during storage, which can affect their nutritional value. Desi *et al*. (2025), reported that inconsistent feed quality can negatively impact the fitness of experimental insects.

The mortality rate, which did not reach 100%, indicates that some individual larvae survived after exposure to the insecticide during the observation period (Table 1). Some surviving larvae successfully developed into pupae. Therefore, pupae were not categorized as dead individuals because they demonstrated successful survival and development after insecticide treatment. According to Karlina *et al*. (2022), *S. frugiperda* is a fast-growing insect species with a high reproductive capacity.

The *Spodoptera frugiperda* larvae used in this study consisted of a mixture of IV- and V-instar larvae. This is a limitation of the study, as differences in larval instars can affect body size, feeding rate, and susceptibility to insecticides. The observed variation in mortality response is likely not solely due to insecticide treatment but may also be influenced by differences in larval developmental stage. According to Berg & Plessis (2022), that larvae show increasing tolerance to insecticides with age and body size.

3.1. Lethal Concentration 50 (LC50) and Lethal Concentration 90 (LC90)

Lethal concentration 50 (LC_{50}) is defined as the concentration required to cause mortality in 50% of a test insect population within a given exposure period. The determination of LC_{50} aims to estimate the concentration of each treatment necessary to achieve 50% mortality of the test insects (Rosandy *et al*., 2024). LC_{90} (Lethal Concentration 90) is defined as the concentration of an insecticide required to kill 90% of the tested insect population.

Table 2. Estimation of Lethal Concentrations (LC) of three carbamate insecticides on *Spodoptera frugiperda*

Insecticide	Slope ± SE	LC_{50}	LC_{90}
Carbaryl	2,34 ± 1,03	14,402	50,625
Methomyl	4,40 ± 1,70	4,811	9,407
Carbofuran	2,74 ± 0,99	5,574	16,367

Note: SE: Standard Error

Based on the probit analysis for LC estimation using SPSS software, differences in LC_{50} and LC_{90} values were observed among the tested insecticides (Table 2). These differences in LC_{50} values indicate that each active ingredient evaluated exhibited different levels of effectiveness in causing mortality in *S. frugiperda*.

The analysis results (Table 2) showed that the active ingredient carbaryl had an estimated LC_{50} value of 14.402 mg a.i./L, while the estimated LC_{90} value was 50.625 mg a.i./L. The active ingredient methomyl exhibited an estimated LC_{50} value of 4.811 mg a.i./L and an estimated LC_{90} value of 9.407 mg a.i./L. Meanwhile, the active ingredient carbofuran had estimated LC_{50} and LC_{90} values of 5.574 mg a.i./L and 16.367 mg a.i./L, respectively. The higher LC_{90} values compared with LC_{50} values observed in all treatments indicate that higher insecticide concentrations are required to achieve effective control of a larger proportion of the tested population.

The active ingredient methomyl showed the lowest LC value compared to the other two active ingredients. According to Ramadhan & Nurhidayah (2022), a low LC value indicates that the active ingredient acts as an acute toxicant and exhibits a strong lethal effect. Furthermore, acute toxicity is also characterized by the short time required for the insecticide to kill insects (Table 3). It can be concluded that methomyl-based insecticides have high toxicity and are highly effective in controlling insect pests.

The estimated LC_{50} and LC_{90} values for the active ingredient carbaryl were relatively higher than those for methomyl and carbofuran. Methomyl showed higher toxicity than carbaryl and carbofuran. According to Slamet *et al*. (2020), the toxicity of a compound is indicated by a lower LC_{50} value.

The insecticides used in this study belong to the same chemical class, namely carbamates. Carbamates work by inhibiting the activity of the cholinesterase enzyme (Alfiansyah *et al*., 2023). Differences in LC_{50} values among carbamate insecticides are thought to be influenced by the characteristics of each active ingredient. Rinjani *et al*. (2025), reported that carbamate insecticides exhibited different LC_{50} values against *Aphis gossypii* populations from Serang District (59%) and Cipocok Jaya District (49%), indicating variation in susceptibility between field populations. Similarly, the present study found differences in LC_{50} values among the tested carbamate insecticides against *S. frugiperda*, suggesting that insecticide susceptibility varies depending on both the insect population and the active ingredient evaluated.

3.2. Lethal Time 50 (LT50) and Lethal Time 90 (LT90)

Lethal Time 50 (LT_{50}) is defined as the time required to cause mortality in 50% of the tested insect population. The estimation of LT_{50} is intended to determine the duration of exposure required for a treatment to kill half of the test population (Rosandy *et al*., 2024). The LT_{90} (Lethal Time 90) value refers to the duration required for an insecticide treatment to cause mortality in 90% of the exposed insect population.

Table 3. Lethal Time (LT) estimates of *Spodoptera frugiperda* after insecticide application

Treatment	Slope ± SE	LT_{50}	LT_{90}
Carbaryl1	10,71 ± 2,03	5,293	6,972
Carbaryl2	9,30 ± 3,46	4,770	6,551
Carbaryl3	8,64 ± 2,60	4,581	6,445
Carbaryl4	10,44 ± 3,24	4,563	6,053
Carbaryl5	7,20 ± 1,95	3,862	5,818
Methomyl1	4,06 ± 1,49	0,729	1,506
Methomyl2	4,54 ± 1,48	0,873	1,671
Methomyl3	6,82 ± 3,31	0,702	1,081
Methomyl4	3,63 ± 1,52	0,672	1,514
Methomyl5	7,92 ± 3,07	0,444	0,644
Carbofuran1	7,75 ± 2,15	4,553	6,663
Carbofuran2	4,68 ± 1,59	3,533	6,629
Carbofuran3	2,94 ± 0,77	2,047	5,584
Carbofuran4	3,12 ± 0,75	1,674	4,307
Carbofuran5	2,53 ± 0,81	1,259	4,035

Note: SE: Standard Error

Based on the probit analysis to estimate the LT value of three insecticide treatments using SPSS software, different time estimates were obtained (Table 3). The results showed that for carbaryl-based insecticides at a concentration of 5%, the estimated LT_{50} was reached on day 5 and LT_{90} on day 6. Meanwhile, at concentrations of 20%, 50%, and 75%, the estimated LT_{50} occurred on day 4, with LT_{90} observed on day 6. At the highest concentration (95%), LT_{50} was reached faster, namely on day 3, while LT_{90} was reached on day 5. These findings indicate that carbaryl shows a relatively slow effect in killing pests.

The results of the probit analysis for LT estimation using SPSS for insecticide treatment with the active ingredient methomyl showed a relatively short lethality time (Table 3). At a concentration of 20%, the estimated LT value increased compared to a concentration of 5%. This increase indicates that, based on the probit model estimation, a longer time is required to reach a certain level of mortality at this concentration. This finding suggests that increasing concentration does not always directly lead to a decrease in LT values.

The LT_{50} value estimated using SPSS for carbofuran indicates that 5% mortality occurs in approximately 4 days (Table 3). This figure decreases to 3 days at the 25% concentration and 2 days at the 50% concentration, while the 75% and 95% concentrations produce an LT_{50} of approximately 1 day. For LT_{90}, mortality at the 5% and 20% concentrations occurs in approximately 6 days, decreasing to 5 days at the 50% concentration and 4 days at the 75% and 95% concentrations.

According to Filho *et al*. (2026), although certain active ingredients exhibit slower lethal effects on insects, additional factors contribute to pest control by reducing key behavioral activities such as long-distance flight, feeding activity, and egg laying. Fiaboe *et al*. (2023), further stated that insecticides may not cause acute mortality. However, their sublethal toxicity can still have significant impacts on insect populations, including behavioral disruption and reduced reproductive success.

Numerically, there was a tendency for the estimated LT value to decrease with increasing concentrations for the three tested insecticides, especially at the highest concentration, which resulted in a faster mortality time compared to other concentrations. However, based on statistical analysis, the concentration treatment did not have a significant effect on *S. frugiperda* larval mortality. The absence of a significant concentration effect is thought to be related to inter-individual variation in the *S. frugiperda* field population in response to insecticide exposure. In addition, heterogeneity in sensitivity between individuals can cause variations in mortality time. Therefore, increasing concentrations within the tested range did not consistently result in accelerated mortality.

Differences in mortality patterns among active ingredients can influence the estimation of toxicological parameters, including LC and LT values. Methomyl showed a very high mortality response from the beginning of the observation period (Table 1), resulting in lower LC and LT values compared to other active ingredients, due to the lower concentrations and shorter exposure times required to achieve a given level of mortality. In contrast, carbaryl and carbofuran showed a relatively slower mortality response, requiring higher concentrations or longer exposure periods to achieve comparable levels of mortality. Sisay *et al*. (2019), reported that carbaryl achieved a mortality rate of only 28% after 72 h of exposure, suggesting relatively low insecticidal efficacy against *S. frugiperda*. However, the rapid mortality response observed with methomyl treatment suggests that LT values should be interpreted with caution, as the variation in time to mortality is more limited.

3.3. Morphological Changes in the Test Insects

S. frugiperda is classified within the order Lepidoptera and family Noctuidae. According to Ria *et al*. (2026), *S. frugiperda* exhibits distinctive morphological characteristics, including an inverted "Y"-shaped mark on the head, a brown body color, and four black spots (pinacula) on the eighth abdominal segment arranged in a rectangular pattern. Each of these black spots bears a small seta (hair-like structure).

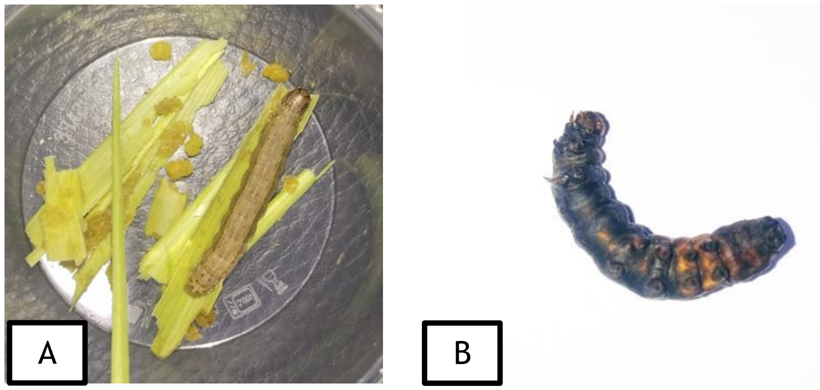

Figure 2. (A) Prior to insecticide application, (B) Following insecticide application

Based on observations, *S. frugiperda* larvae exposed to insecticides exhibited visible changes, including changes in body shape, color, and texture. After being fed insecticide-treated food, the larvae exhibited behavioral changes characterized by decreased activity, uncoordinated movements, and seizures before death. According to Mursyidin *et al*. (2026), symptoms such as seizures, paralysis, and relatively rapid death occur due to impaired nerve impulse transmission in larvae exposed to insecticides.

Dead larvae are observed in a characteristic curved body position. The color change initially occurs in the head area and then progresses until the entire body darkens. After a few days, the larva's body becomes soft and crumbles easily to the touch, accompanied by a foul odor.

4. Conclusion

This study demonstrated that methomyl was the most effective carbamate insecticide against field populations of *S. frugiperda* in Serang Regency, indonesia. The tested *S. frugiperda* population exhibited reduced susceptibility to carbaryl, indicating possible resistance. In addition, insecticide exposure induced characteristic morphological changes in larvae.

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