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Research Article

Efficacy of Several Synthetic Insecticides against Mortality of the Fall Armyworm *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae)

Efikasi Beberapa Insektisida Sintetik terhadap Mortalitas Hama Ulat Grayak Jagung Spodoptera frugiperda (Smith) (Lepidoptera: Noctuidae)

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Abstract: *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae) is a major polyphagous corn pest that has caused significant corn yield losses in Indonesia. Synthetic insecticides are still the primary choice, but their effectiveness in the field against *S. frugiperda* larval mortality is determined by the active ingredient and concentration used. This study aimed to evaluate the efficacy of several synthetic insecticides with the active ingredients cypermethrin, abamectin, and a combination of emamectin benzoate + chlorfenapyr on the mortality and time-response of *S. frugiperda* larvae on corn plants through laboratory testing. The study used a completely randomized design (CRD) with six treatments and four replicates. Larval mortality was observed at 6, 12, 24, 36, and 72 hours after treatment (HAT) and analyzed using the Kruskal-Wallis test at a significance level of 5% ($\alpha = 0.05$). The results showed that corrected mortality at 72 HAT ranged from 85–100% across synthetic insecticide treatments, caused mortality in *S. frugiperda* larvae with symptoms such as decreased feeding activity, paralysis, body color changes, and shriveled death. The combination of emamectin benzoate + chlorfenapyr at the highest consentration caused 100% mortality within 12 HAT, whereas cypermethrin reached complete mortality at 24 HAT. Abamectin exhibited a more gradual increase in mortality up to 72 HAT. Numerically, the combination treatment demonstrated a more rapid mortality response than the single active ingredient treatments. These results indicate that all tested synthetic insecticides were effective against third instar S. *frugiperda* larvae, although differences in the speed of mortality response were observed among treatments.

Keywords: chemical control, corn pest, emamectin benzoate, insecticide active ingredients, insecticide management

Abstrak: *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae) merupakan hama utama jagung yang sangat polifag dan telah menyebabkan kehilangan hasil produksi jagung yang cukup signifikan di Indonesia. Penggunaan insektisida sintetik masih menjadi pilihan utama, tetapi efektivitasnya di lapangan terhadap mortalitas larva *S. frugiperda* ditentukan oleh bahan aktif dan konsentrasi yang digunakan. Penelitian ini bertujuan untuk mengevaluasi efikasi beberapa insektisida sintetik berbahan aktif sipermetrin, abamektin, dan kombinasi emamektin benzoat + klorfenapir terhadap mortalitas dan respon waktu kematian larva *S. frugiperda* pada tanaman jagung melalui pengujian laboratorium. Penelitian menggunakan Rancangan Acak Lengkap (RAL) dengan enam perlakuan dan empat ulangan. Mortalitas larva diamati pada 6, 12, 24, 36, dan 72 jam setelah perlakuan (JSP) dan dianalisis menggunakan uji Kruskal-Wallis pada taraf signifikansi 5% ($\alpha = 0,05$). Hasil menunjukkan bahwa mortalitas terkoreksi pada 72 JSP mencapai 85–100% pada seluruh perlakuan insektisida sintetik, menyebabkan kematian pada larva *S. frugiperda* dengan gejala berupa penurunan aktivitas makan, kelumpuhan, perubahan warna tubuh, dan mati mengkerut. Kombinasi emamektin benzoat + klorfenapir pada konsentasi tertinggi menyebabkan mortalitas 100% dalam 12 JSP, sedangkan sipermetrin mencapai 100% pada 24 JSP dan abamektin menunjukkan peningkatan mortalitas bertahap hingga 72 JSP. Secara numerik, kombinasi bahan aktif menunjukkan respons kematian lebih cepat dibandingkan bahan aktif tunggal. Temuan ini mengindikasikan bahwa seluruh

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insektisida sintetik yang diuji efektif terhadap larva instar tiga *S. frugiperda*, meskipun terdapat perbedaan dalam kecepatan respons kematian antarperlakuan.

Kata kunci: bahan aktif insektisida, emamektin benzoat, hama jagung, manajemen insektisida, pengendalian kimiawi

INTRODUCTION

The fall armyworm *Spodoptera frugiperda* (Smith) (Lepidoptera: Noctuidae) is a major corn pest that has attacked corn crops in various parts of the world (Goergen et al., 2016). This pest was first reported in Indonesia on March 26, 2019, in West Pasaman Regency, West Sumatera (Sartiami et al., 2020), and the damage rate reached 100% at the beginning of its invasion in Lampung Province (Trisyono et al., 2019). To date, attacks have been reported on corn fields in various regions, including in eastern Indonesia, ranging from 70–100% (Mukkun et al., 2021; Noerfitryani et al., 2023; Mursyidin et al., 2024; Puu et al., 2025). The attack rate of *S. frugiperda* is reported to be higher in the early vegetative phase than in the generative phase (Supartha et al., 2022; Herlinda et al., 2023). This pest is polyphagous, has a short life cycle, the ability to migrate long distances, and high reproductive capacity (Kumela et al., 2018; Montezano et al., 2018), so it has the potential to cause significant yield losses if not controlled quickly and appropriately (Trisyono et al., 2019; Wan et al., 2021).

Pest control efforts for *S. frugiperda* at the farmer level still rely on the use of synthetic insecticides because they are considered practical and show faster and more efficient results in terms of economics and time (Kumela et al., 2018; Zhang et al., 2021). However, intensive and inappropriate use can potentially cause environmental degradation (Togola et al., 2018; Harrison et al., 2019) , trigger pest resistance and resurgence (Boaventura et al., 2020), and kill natural enemies (Ricupero et al., 2020). Several groups of synthetic insecticides commonly used in the control of *S. frugiperda* include pyrethroids (e.g., cypermethrin), avermectins (e.g., abamectin), and semi-synthetic avermectin derivatives such as emamectin benzoate (Rwomushana et al., 2018; Togola et al., 2018). The combination of emamectin benzoate and chlorfenapyr was selected in this study because it represents a dual mode-of-action formulation that is increasingly adopted in corn pest management programs. Emamectin benzoate acts on glutamate-gated chloride channels causing rapid paralysis, whereas chlorfenapyr disrupts oxidative phosphorylation and ATP production (Kambrekar et al., 2016; IRAC, 2021).

Various studies report that the effectiveness of synthetic insecticides against *S. frugiperda* can be influenced by the type of active ingredient, concentration, application method, and larval stage used (Deshmukh et al., 2020; Khanal et al., 2024; Syahrani et al., 2025). Generally, young larval instars are more susceptible to synthetic insecticide treatment (Day et al., 2017) than older instars, which have thicker and denser cuticles or

skin (Sumaryati et al., 2023), so testing using the early instar phase is important to obtain the basis for the proper application of insecticides. In addition, differences in the effectiveness of active ingredients also determine control strategies in the field (Agustini et al., 2024), especially at severe infestation levels that require rapid pest population reduction (Trisyono et al., 2019). Although these active ingredients have been widely used, scientific data on mortality and time-to-death responses under laboratory conditions are still limited. Therefore, this study aims to evaluate the efficacy of several synthetic insecticides with the active ingredients cypermethrin, abamectin, and a combination of emamectin benzoate + chlorfenapyr against the mortality and time response to death of *S. frugiperda* larvae on corn plants through laboratory testing. Unlike previous efficacy studies conducted in Indonesia, this study applies a combined exposure method that more closely simulates field exposure conditions. This "double exposure" approach provides a more representative assessment of the performance of synthetic insecticides against *S. frugiperda* larvae under field-relevant conditions.

MATERIALS AND METHODS

Time and Location

This study was conducted in January–February 2026. Samples of *S. frugiperda* larvae were obtained from corn crops that were not treated with pesticides in Pemongkong Village, Jerowaru Subdistrict, East Lombok Regency, West Nusa Tenggara (8°53'39"S, 116°30'21"E) at an altitude of 5 m above sea level. The propagation of test larvae and mortality testing of *S. frugiperda* larvae were carried out at the Plant Protection Laboratory, Faculty of Agriculture, Mataram University, at a temperature of 26–30C, relative humidity (RH) of 70–90%, and a photoperiod of 12:12 hours (light: dark).

Research Design

This experiment used a Completely Randomized Design (CRD) with six treatments and four replications, resulting in 24 experimental units, with each unit using 10 individuals of third instar *S. frugiperda* larvae. The tested concentrations were based on recommended field dosages provided on product labels and supported by previous efficacy studies. These concentrations were selected to represent field-relevant application rates. Each insecticide was applied according to its labeled field concentration. Detailed information on the concentration, formulation, active ingredient, and application rate of each product is provided in Table 1.

Table 1. Synthetic insecticide treatments, active ingredients, and consentration used in the test

Code	Active Ingredient	Consentration
T1	Distilled water	Control
T2	Cypermethrin (50 g/L)	1 mL/L
T3	Abamectin (18 g/L)	1 mL/L
T4	Emamectin benzoate (20 g/L) + chlorfenapyr (100 g/L)	0,75 ml/L
T5	Emamectin benzoate (20 g/L) + chlorfenapyr (100 g/L)	1,5 mL/L
T6	Emamectin benzoate (20 g/L) + chlorfenapyr (100 g/L)	2,25 mL/L

Sampling and Propagation of Test Larvae

Samples of late instar (instar 5 or 6) *S. frugiperda* larvae were collected from corn leaf rolls or growing points marked by the presence of frass (Maharani et al., 2019; Trisyono et al., 2019). Larvae obtained in the field were collected in plastic containers (height = 4.5 cm, diameter = 6 cm) and fed fresh corn leaves. The larvae were taken to the laboratory to be reared until they developed into adults or adult moths. Each larva was placed individually in each plastic container to avoid larval cannibalism.

The larvae were fed corn leaves that were replaced daily, and their frass were cleaned up. The larvae that develop into pupae are transferred to a rearing container (length = 17 cm, width = 11 cm, height = 8.5 cm) by selecting male and female pupae, which are distinguished by the difference in the distance between the anal and genital openings on the abdomen (Sumaryati et al., 2023). The pupae were reared until they developed into imagoes. The imagoes were fed a 20% honey solution absorbed into cotton wool suspended inside the container. The imagoes were fed until they died. As a medium for female imagoes to lay their eggs, opaque paper was placed inside the container and attached to the container wall. Egg harvesting was carried out every day at 24-hour intervals until the imagoes stopped producing eggs. The egg groups were transferred to new plastic containers (length = 9 cm, width = 6.5 cm, height = 4 cm) for larval hatching and lined with tissue paper to maintain the humidity of the container. The hatched larvae were mass-reared and fed fresh corn leaves or young corn cobs until they reached the third instar stage, after which they were used as test larvae to reduce variability in susceptibility. Rearing was continued until a sufficient number of larvae for bioassay was obtained. F1 generation larvae derived from field-collected parents were used in the bioassay to reduce variability associated with field populations.

Application

The insecticide solutions were prepared according to the recommended dosages and diluted in 1 L of water. A surfactant (Besmor; active ingredient: sodium 2-ethylhexyl sulfosuccinate) was added at 2 mL/L to all insecticide treatments. The control treatment consisted of distilled water without insecticide or surfactant. Application is carried out by combining the insect spray method using a hand sprayer with a uniform spray volume so that the larvae's bodies are evenly wet, and the provision of corn leaves that have been dipped in insecticide solution as a simulation of double exposure in the field. Corn leaves were dipped in the synthetic insecticide solution for 10 seconds, then air-dried for approximately 15 minutes at room temperature before being provided to the larvae. Each replicate used 10 individuals of *S. frugiperda* third instar larvae, requiring 40 larvae for each treatment. Larval mortality observations were conducted at 6, 12, 24, 36, and 72 hours after treatment (HAT).

Observation Parameters

Observations were made by calculating the percentage of *S. frugiperda* larvae that died (mortality) at 6, 12, 24, 36, and 72 HAT. Larvae were considered dead if they showed no response to mechanical stimulation. Supporting symptoms such as decreased feeding activity, paralysis, and changes in body color were recorded as supporting data. The percentage of *S. frugiperda* larvae mortality was calculated using the following formula:

$$M = \frac{\Sigma n}{\Sigma N} \times 100\%$$

M = mortality (%); n = number of test larvae that died; N = number of test larvae observed

The Abbott (1925) formula is used if there is mortality in the control treatment with control mortality in the range of >5% to ≤20%, and corrected mortality is calculated using the following formula:

$$Mt = \frac{Mp - Mk}{100 - Mk} \times 100\%$$

Mt= corrected mortality (%); Mp = mortality in treatment (%); Mk = mortality in control (%)

Data Analysis

Larval mortality data of *S. frugiperda*, expressed as a percentage, were analyzed using the non-parametric Kruskal-Wallis test at a significance level of 5% (α = 0.05) to determine differences between treatments at each observation time. When significant differences were detected, Dunn's post hoc test with Bonferroni correction was applied.

All data were presented as means ± standard error (SE) and analyzed using Minitab software version 22.

RESULTS AND DISCUSSION

Larval Mortality of *S. frugiperda*

Based on the results of the study, synthetic insecticide treatment can cause mortality in *S. frugiperda* larvae with changes in behavior and morphological symptoms, namely decreased appetite, slow movement, larvae appearing to avoid corn leaf feed, changes in body color, and death in a shriveled condition. In all synthetic insecticide treatments, feeding activity was drastically reduced compared to the control, as indicated by minimal feeding damage and absence of larval feces (frass) production. In addition, exposure to synthetic insecticides caused morphological changes from healthy and actively feeding larvae (Figure 1A) to shriveled and softened larvae with black spots on the abdomen (Figure 1B) and a gradual change in color to darker or black (Figure 1C).

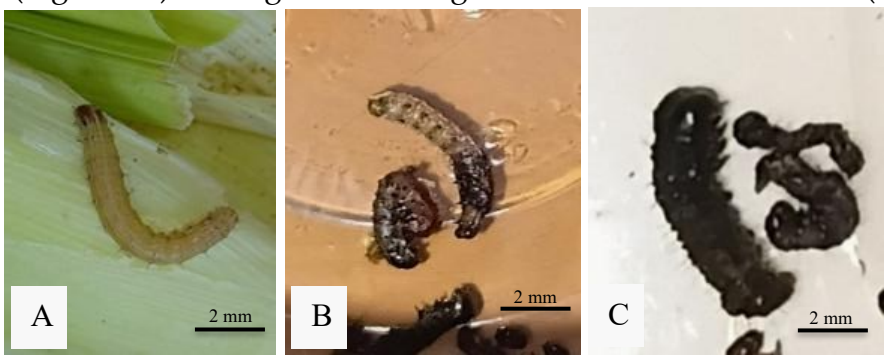

Figure 1. Conditions of *S. frugiperda larvae*, A: healthy and actively feeding, B: wet death with black spots on the abdomen, C: dry death with blackened body.

The observed paralysis symptoms are consistent with the known modes of action of the applied insecticides. For example, emamectin benzoate, a member of the avermectin group, acts by activating glutamate-gated chloride channels, leading to increased chloride ion influx, neuronal hyperpolarization, disruption of nerve signal transmission, flaccid paralysis, and eventual death. Other neurotoxic insecticides may affect different targets within the insect nervous system, such as voltage-gated sodium channels or acetylcholine-mediated synaptic transmission, resulting in impaired motor coordination and feeding inhibition. These symptoms are indicative of neurotoxic effects, although they do not exclusively confirm a specific mode of action.

The results of this study are in accordance with Syahrani et al. (2025) and Fitriani et al. (2023) that larval mortality is caused by the active ingredient of the insecticide applied, resulting in physiological disturbances in the form of decreased feeding activity and morphological changes in the larvae, causing them to shrivel and darken in color. According to Dadang & Prijono (2008) and Azwana et al. (2019), leaves dipped in insecticide solution can deter larvae from eating them due to their bitter taste and

pungent odor. This is because synthetic insecticide active ingredients are able to penetrate the leaf tissue of the feed, thereby exerting residual activity on *S. frugierda* larvae that consume or detect the aroma of the leaves (Mukanga et al., 2024).

Insecticide application synthetic based on active cypermethrin, abamectin and emamectin benzoate + chlorfenapyr showed an effect on the mortality of *S. frugiperda* larvae throughout the observation period (6–72 HAT). In the control treatment, mortality exceeded 5% at several observation times (Table 2), so the average mortality data for the treatment was corrected using the Abbot formula, which was used as the basis for further statistical analysis. Although control mortality reached 20% at 72 HAT, treatment mortality was corrected using Abbott's formula. However, this level of control mortality exceeds commonly accepted thresholds for bioassay reliability and may reduce confidence in the results at later observation times. Therefore, the data at 72 HAT should be interpreted with caution. The elevated control mortality may be associated with handling or environmental stress during the experiment.

Table 2. Average mortality (%) ± SE of *S. frugiperda* larvae at various observation times of observation

Treatment	Mortality (%) ± SE				
	6 HAT	12 HAT	24 HAT	36 HAT	72 HAT
T1	5,0 ± 2,9	17,5 ± 5,0	17,5 ± 5,0	17,5 ± 5,0	20,0 ± 5,8
T2	75,0 ± 5,0	90,0 ± 4,1	100,0 ± 0,0	100,0 ± 0,0	100,0 ± 0,0
T3	22,5 ± 8,5	30,0 ± 9,1	65,0 ± 4,8	87,5 ± 2,4	90,0 ± 4,1
T4	100,0 ± 0,0	100,0 ± 0,0	100,0 ± 0,0	100,0 ± 0,0	100,0 ± 0,0
T5	85,0 ± 5,0	100,0 ± 0,0	100,0 ± 0,0	100,0 ± 0,0	100,0 ± 0,0
T6	95,0 ± 2,9	100,0 ± 0,0	100,0 ± 0,0	100,0 ± 0,0	100,0 ± 0,0

HAT = hours after treatment, SE = standard error.

In general, the corrected mortality pattern of *S. frugiperda* larvae to synthetic insecticide treatments showed an increase over the observation period. This is consistent with Sisay et al. (2019), who found that the mortality percentage of *S. frugiperda* larvae to toxic residues from synthetic insecticides tended to increase during the observation period. At 6 HAT, treatment T4 with the active ingredients emamectin benzoate + chlorfenapyr produced the highest mortality (100%), followed by T6 and T5 with the same active ingredients at 94.7% and 84.2%, respectively, T2 with the active ingredient cypermethrin (73.7%), and the lowest in T3 with the active ingredient abamectin (18.4%). At 12 HAT, treatments T4, T5, and T6 had reached 100% mortality, while T2 (87.9%) and

the lowest in T3 (15.2%). At 24 to 72 HAT, all treatments reached 100% mortality, except for treatment T3, which showed gradual mortality until it reached the highest mortality of 87.5% at 72 HAT.

Table 3. Corrected mortality (Abbot) of *S. frugiperda* larvae (%) ± SE at various observation times

Treatment	Corrected mortality (%) ± SE				
	6 HAT	12 HAT	24 HAT	36 HAT	72 HAT
T2	73,7 ± 5,3	87,9 ± 4,5	100,0 ± 0,0	100,0 ± 0,0	100,0 ± 0,0
T3	18,4 ± 9,0	15,2 ± 9,7	57,6 ± 5,3	84,8 ± 2,6	87,5 ± 4,5
T4	100,0 ± 0,0	100,0 ± 0,0	100,0 ± 0,0	100,0 ± 0,0	100,0 ± 0,0
T5	84,2 ± 5,3	100,0 ± 0,0	100,0 ± 0,0	100,0 ± 0,0	100,0 ± 0,0
T6	94,7 ± 3,1	100,0 ± 0,0	100,0 ± 0,0	100,0 ± 0,0	100,0 ± 0,0

Figures in the same column are not significantly different based on the Kruskal-Wallis test at a significance level of 5% ($p > 0.05$). Mortality values have been corrected using the Abbott formula because mortality in the control group was >5%. HAT = hours after treatment, SE = standard error.

The high larval mortality rates in T4, T5, and T6 indicate that the combination of the active ingredients emamectin benzoate + chlorfenapyr is the most effective synthetic insecticide in this study, consistent with the findings of Khanal et al. (2024) and Susanto et al. (2021) which found that 100% mortality was achieved at 24 HAT and included the most effective synthetic insecticide treatment for *S. frugiperda* larval mortality. The T2 treatment with the active ingredient cypermethrin showed higher mortality than T3 with the active ingredient abamectin, which differs from the findings of Idrees et al. (2022), who found that cypermethrin mortality tended to be lower than abamectin at 24 to 72 HAT. This discrepancy may be related to differences in experimental conditions between studies, such as formulation types and bioassay environments. In the present study, larvae were standardized at the third instar stage, which may have reduced variability in susceptibility and contributed to the observed mortality levels. However, as no comparison across different larval instars was conducted, this factor should be interpreted with caution (Talha et al., 2025). This is because young instar larvae do not yet have thick and dense cuticles or skin (Sumaryati et al., 2023), making them more susceptible to exposure to applied synthetic insecticides (Day et al., 2017). In addition, the addition of The active ingredient sodium 2-ethylhexyl sulfosuccinate. a concentration of 2 ml/L to all insecticide treatments solution is thought to increase the solution's adhesion to the larvae's bodies and the surface of the feed leaves, thereby increasing the

effectiveness of the active ingredient in coming into direct contact with the larvae's integument and accelerating the penetration of toxic compounds (Silva et al., 2024).

Based on the results of the Kruskal-Wallis test ($\alpha = 0.05$), there was no significant difference between the treatments of synthetic insecticide concentrations on the mortality of *S. frugiperda* larvae at all observation times ($p > 0.05$). This indicates that although numerically mortality increased in the synthetic insecticide treatment compared to the control, the difference in concentration between treatments was not statistically significant enough to be considered a significant difference. Statistically, the effectiveness of each active ingredient was relatively equivalent under laboratory conditions, but biologically there were differences in the speed of action that were important for interpreting the results in the field. Although the Kruskal-Wallis test indicated no statistically significant difference among treatment at 6 HAT ($p > 0.05$), a substantial numerical difference was observed (e.g., T4 = 100% and T3 = 18.4%). This apparent discrepancy between numerical and statistical outcomes may be attributed to variability among replicates, as reflected by the relatively high standard error values, and the limited sample size used in each treatment.

Time Mortality Dynamics

The time mortality curve shows that treatments T4, T5, and T6 containing the active ingredients emamectin benzoate + chlorfenapyr have the fastest efficacy, as indicated by high mortality reaching 100% at the start of observation (6–12 HAT) and remaining stable up to 72 HAT (Figure 2).

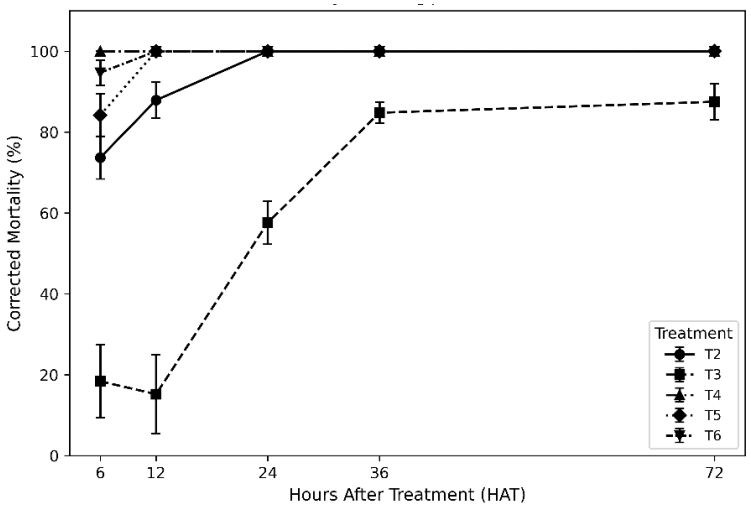

Figure 2. Mortality curve of *S. frugiperda* larvae corrected for various synthetic insecticide treatments based on observation time (6–72 HAT), presented as mean ± SE.

Emamectin benzoate is known to act on the nervous system by activating glutamate-gated chloride channels (GluCls) and gamma- amino butyric acid (GABA) receptors in the chloride channels in the insect synapse membrane, causing feeding cessation and irreversible paralysis, and becoming a residue on leaves by forming a reservoir (Kambrekar et al., 2016). Emamectin benzoate is an avermectin insecticide consisting of semi-synthetic homologous microlides derived from the natural fermentation product of actinomycetes, *Streptomyces avermitilis* (Stavrakaki et al., 2022). The unique mode of action of this class of insecticides is very effective against insect pests that show resistance to other classes such as organophosphates and pyrethroids (Khalil, 2013). Meanwhile, chlorfenapyr (IRAC Group 13) is a pyrole insecticide that works by inhibiting the production of adenosine triphosphate (ATP) in insects and disrupting cellular metabolism (IRAC, 2021).

Treatment T2 with the active ingredient cypermethrin showed fairly rapid mortality at the beginning of the observation period (6–12 HAT), exceeding 70% and reaching 100% at 24 HAT (Figure 2). The high mortality rate within 24 HAT indicates that the test larvae are still sensitive to synthetic pyrethroid insecticides. This mortality pattern indicates that cypermethrin has a rapid knockdown effect by attacking the insect nervous system through the inhibition of sodium channel function, thereby disrupting nerve cell impulse transmission, causing the larvae to experience convulsions, paralysis, and ultimately death in a short time (Chourasiya & Mahobiya, 2020; IRAC, 2021). In contrast, the T3 treatment with the active ingredient abamectin showed slower mortality, which increased over time to reach 87.5% at 72 HAT (Figure 2). Abamectin is an avermectin insecticide that generally works by preventing the transmission of electrical impulses in muscles and nerves, by enhancing the effect of glutamate on insect-specific chloride channels, causing insects to become paralyzed and die slowly. This slow mortality pattern is consistent with the character of abamectin, which is known as a slow-acting but effective insecticide (Batiha et al., 2020; IRAC, 2021).

CONCLUSIONS

All synthetic insecticide treatments showed high efficacy against *S. frugiperda* larval mortality, causing changes in larval behavior and morphology. The combination of emamectin benzoate + chlorfenapyr (T4) caused rapid mortality, reaching 100% within 6 HAT, whereas abamectin required up to 72 HAT to reach 87.5% mortality. However, statistical analysis showed no significant differences between treatments, but the dynamics of mortality over time indicated differences in the mode of action of each active ingredient, thereby affecting their effectiveness against *S. frugiperda* larvae in laboratory scale. These results suggest that, although overall efficacy was comparable, the temporal patterns of mortality may differ among insecticides, potentially reflecting differences in their modes of action. The rapid mortality observed in the emamectin benzoate +

chlorfenapyr treatment indicates its potential for faster suppression under controlled conditions, although further validation under field conditions is required before making practical recommendations.

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