ASIAN JOURNAL OF ETHNOBIOLOGY
Volume 8, Number 2, December 2025
Pages: 222-229

E-ISSN: 2580-4510
DOI: 10.13057/asianjethnobiol/y080208

Ethnobotanical validation of plant extracts for sustainable management of fall armyworm

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Manuscript received: 17 August 2025. Revision accepted: 24 September 2025.

Abstract. *Labonete HJP, Ancheta DJ, Modina RMR, Yongco JE, Torres MAJ, Demayo CG. 2025. Ethnobotanical validation of plant extracts for sustainable management of fall armyworm. Asian J Ethnobiol 8: 222-229.* Ethnobotanical practices offer essential insights for pest management in smallholder farming. In the Philippines, the use of chili (C*apsicum frutescens*), madre de cacao (*Gliricidia sepium*), and lemongrass (*Cymbopogon citratus*) as botanical insecticides is based on farmers' knowledge and indigenous traditions, yet their effectiveness against transboundary crop pest fall armyworm (*Spodoptera frugiperda*) remains untested. To address this gap, the sublethal effects of crude botanical extracts on third-instar *S. frugiperda* larvae were studied under laboratory conditions. All extracts produced dose-dependent sublethal effects: lemongrass caused the strongest feeding suppression (28.7%) and induced developmental malformations in larvae (5.0%), pre-pupae (6.3%), pupae (14.3%), and adults (7.1%); chili delayed development by up to 7 days and reduced survival to 45%; and madre de cacao deterred feeding mainly in dual-choice assays (antifeedant index=49.2%), suggesting efficacy for intercropping. This is the first validation of crude aqueous extracts for *S. frugiperda*, demonstrating the potential of farmer-based botanical insecticides as an addition to integrated pest management (IPM). The findings highlight how locally adapted practices, grounded in ancestral and community knowledge, can contribute to agroecology and strengthen food security by advancing sustainable, low-cost, and eco-friendly alternatives to synthetic pesticides. However, to fully realize this potential, further field-based trials and phytochemical characterization are crucial and should be the focus of future research.

Keywords: Biological parameters, crude extracts, fall armyworm, natural insecticide, traditional knowledge

INTRODUCTION

Ethnobotanical insecticides are gaining renewed attention for their ability to merge ecological safety with cultural relevance, building on the long-standing reliance by indigenous communities and smallholder farmers who use insecticidal plants as affordable, effective, and biodegradable alternatives to synthetic applications. For thousands of years, crude botanical extracts rich in secondary metabolites have provided antifeedant effects, target specificity, and preservation of natural pest enemies, resulting in residue-free crops, enhanced biodiversity, and sustainable agriculture (Pavela 2016). This is evident in the Philippines, an agricultural country that harbors thousands of endemic vascular plant species used by diverse ethnic groups. In a recent review, 112 primarily native plant species have been documented to be utilized as botanical insecticides by indigenous people (IPs) and local farmers in the Philippines, with *Capsicum*, *Cymbopogon*, and *Gliricidia sepium* as the most cited genera and species (Labonete et al. 2025).

Among the promising botanicals, *Cymbopogon citratus* (lemongrass), *Capsicum frutescens* (chili), and *Gliricidia sepium* (madre de cacao) stand out as culturally and agriculturally significant species. *Cymbopogon citratus* is among the most widely adopted botanicals, integrated by farming communities into intercropping systems for its natural repellency. At the same time, aqueous leaf extracts mixed with soap are sprayed on crops for its strong aromatic and insecticidal properties. In contrast, *C. frutescens* has long been favored by rice and chili farmers, with crude fruit extracts commonly sprayed on leaves for its pungent effects that irritate insect pests. *Gliricidia sepium*, on the other hand, serves as a living barrier in intercropping, provides aqueous leaf sprays, and is burned for defogging. Despite their widespread cultural significance and long-standing use by farming communities, crude aqueous extracts remain largely untested in controlled experiments, creating a gap between traditional practice and scientific validation. The growing interest in natural plant products underscores the urgent need for scientific evaluation of their bioactive compounds (Ejeta et al. 2021), which are selective and environmentally safe, making them valuable for sustainable pest management, food security, and agroecosystem development through continued cultivation and mixed-cropping. With the rise of transboundary pests and diseases, the long-standing use of *C. citratus*, *C. frutescens*, and *G. sepium* across regions highlights their promise as candidates for laboratory verification.

The fall armyworm *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) has rapidly emerged as a major transboundary pest in Southeast Asia since it arrived in 2018, causing widespread damage to staple cereal crops (Kusano et al. 2025). In the Philippines, infestations threatening millions of hectares of corn and rice have driven heavy reliance on chemical pesticides, highlighting the need for stronger, eco-friendly, plant-based alternatives (Labonete et al. 2024). Despite the long-standing ethnobotanical use of *C. citratus, C. frutescens,* and *G. sepium* by farming communities as crude aqueous sprays or intercrop repellents, their potential impact on *S. frugiperda* remains largely unexplored under controlled conditions. This study hypothesizes that these crude extracts, prepared using traditional methods with soap, exert measurable sublethal effects on the pest's growth, development, and feeding behavior. Larval responses in dual-choice and no-choice feeding assays, along with pupal and adult biological parameters and morphological development, are assessed to connect local practices with experimental validation.

MATERIALS AND METHODS

Study area

Insect rearing, dose-setting experiments and bioassays were conducted at the Center of Integrative Health (CIH) Laboratory, Premier Research Institute of Science and Mathematics (PRISM), Mindanao State University–Iligan Institute of Technology (MSU-IIT), Iligan City, Philippines under ambient conditions (28.6±5.6°C; 70-80% RH) optimal for larval development (Pavana et al. 2023). Crude botanical extract preparation and data collection were performed at the Molecular Ecology and Physiology Laboratory, PRISM, MSU-IIT.

Spodoptera frugiperda culture

Sixth-generation corn-reared *Spodoptera frugiperda* larvae from Davao Oriental State College of Science and Technology, Mati, Davao Oriental, were transported to the CIH Laboratory, PRISM, MSU-IIT. Larvae were reared under controlled conditions (28.6±5.6°C; 70-80% RH; 16:8 L:D photoperiod) until pupation, fed with clean castor (*Ricinus communis*) leaves. Castor leaves were selected as a highly suitable host for *S. frugiperda*, supporting rapid development, high fecundity, balanced sex ratio, and zero larval mortality under laboratory conditions (Salem et al. 2023; Tura et al. 2025). Pupae were placed in 100 mL tissue-lined containers. Upon emergence, adult moths were provided with a 10% honey solution and a potted two-week-old yellow corn plant for oviposition. Eggs were collected every two days by cutting corn leaves, then placed in small containers for cohort rearing. Larval cohorts were standardized by monitoring head capsule molting every 12 h. Bioassays used third-instar larvae starved for 4 h, with fresh, clean, untreated castor leaves as test material. Ethics clearance was granted by the MSU-IIT Research Integrity and Compliance Office, with an IACUC protocol exemption (202500031B).

Ethnobotanical basis

The test plants were selected based on a recent ethnobotanical review of pesticidal plants in the Philippines (Labonete et al. 2025), complemented by observations of local farming practices in Iligan City, Northern Mindanao. Madre de cacao (*G. sepium*) is collected from an organic intercrop system as a plant barrier. At the same time, chili (*C. frutescens*) fruits and lemongrass (*C. citratus*) stalks and leaves are purchased through organic farmers' markets, utilized for household and crop protection. Correct plant identification was certified by a botanist from the Department of Biological Sciences (DBS), MSU-IIT. Crude extracts were prepared following traditional methods.

Preparation of crude extracts

Leaves of madre de cacao (*G. sepium*), fruits of chili (*C. frutescens*), and stalks and leaves of lemongrass (*C. citratus*) were shade-dried, ground to a fine powder, and 10% w/v extracts were prepared by soaking 100 g of powder in 1 L of water containing 0.1% Tween 80 for 24 h at room temperature (Phambala et al. 2020). This technique provides a safe, cost-effective way to utilize plant bioactive compounds for experimental evaluation. Extracts were filtered, stored in cool, dark conditions, and diluted to target concentrations for dose-setting and bioassays. Methomyl, an insecticide effective against *S. frugiperda* (Salem et al. 2023), was used as the positive control, and distilled water served as the negative control.

Experimental setup

Feeding preference bioassays followed a Randomized Block Design (RBD) with third-instar larval cohort identified by hatch date as the block. Two factors were considered: (i) the botanical extract applied (*G. sepium*, *C. frutescens*, *C. citratus*); and (ii) choice type (dual-choice, no-choice), with 20 replicates per treatment combination. Larval growth and development assays used a Completely Randomized Design (CRD) with five treatments: three botanical extracts, positive control (methomyl), negative control (distilled water), with twenty 3rd instar single-larval replicates per treatment.

Dose-setting experiment to determine sub-lethal concentrations

A preliminary dose-setting experiment was conducted to determine extract concentrations for subsequent bioassays and estimate LC_{30} values, following established approaches for sublethal testing (Pavana et al. 2023). LC_{30} was selected as a low lethal concentration to assess antifeedant and developmental effects without causing high mortality, consistent with recommendations for integrated pest management studies (Desneux et al. 2007). Third-instar larvae, pre-starved for 4 h, were used for all assays. Initial toxicity screening involved five concentrations (0.1, 0.5, 1, 5, and 10%), prepared by diluting the extracts in distilled water. Twenty single-larval replicates per treatment were maintained in ventilated plastic containers. Castor (*R. communis*) leaf discs (5 cm diameter, ~1.5 g) were dipped in the treatments, shade-dried for 10 min, before introducing them to the larvae. Untreated leaves served as negative controls, while the positive control, methomyl, was applied at an LC_{30} based on Salem et al. (2023) and computed from lab results. Leaves were replaced every 24 h. Total mortality was assessed at 120 h, with non-responsive larvae considered dead. Rates were corrected using Abbott's formula, and log concentration–mortality regression lines were generated to calculate LC_{30} values for subsequent experiments.

Antifeedant experiments: Dual-choice and no-choice assays

Antifeedant activity was evaluated using the LC_{30} concentrations of crude botanical extracts. Castor leaf discs were treated and shade-dried for 10 min: 2.5 cm diameter (~0.7 g) discs for dual-choice assays and 5 cm diameter (~1.5 g) discs for no-choice assays. In the dual-choice test, a treated (T) and an untreated (C, labelled as UT) disc were presented to a single larva, with feeding observed every 3 h or for a maximum of 24 h until ~50% of one disc was consumed. No-choice assays provided only treated discs. Each treatment was replicated 20 times under controlled conditions. Initial and final disc weights were recorded, and the percentage of leaf area consumed was calculated. Mortality from positive controls was corrected using Abbott's formula, with all negative values set to zero. Antifeedant activity was expressed as a percentage, where higher values indicate stronger effects. The antifeedant index formula is:

$$\text{Antifeedant Index} = \frac{(C-T)}{(100-C)} \times 100$$

Sublethal effects on development and biological parameters

Surviving *S. frugiperda* larvae from the no-choice assay were used to assess sublethal effects of the crude botanical extracts on larval development and life cycle progression. Larvae were continuously exposed to treated castor (*R. communis*) leaf discs (diameter=5 cm, weight ≈ 1.5 g), with fresh leaves replaced every 24 h. Daily observations included the weight of the leaves consumed, the weight of the larvae, and the duration of feeding up until the sixth instar. Biological parameters included weight, developmental duration, survival, mortality, emergence, and malformations across larval, prepupal, pupal, and adult stages. Oviposition and full life cycle assessment were not conducted due to the lack of rearing cages and facilities, but the measured parameters provide valuable insights into insect development under controlled conditions. The formulas provided below were used to calculate several biological parameters:

$$\text{Survival/Emergence (\%)} = \frac{\text{Number of (larvae,pupae,adult) survived}}{\text{Total number of (larvae,pupae,adults)}} \times 100$$

$$\text{Mortality (\%)} = \frac{\text{Number of dead (larvae,pupae,adults)}}{\text{Total number of (larvae,pupae,adults)}} \times 100$$

$$\text{Malformed (\%)} = \frac{\text{Number of malformed(larvae,pupae,adults)}}{\text{Total number of (larvae,pupae,adults) emerged}} \times 100$$

Statistical analysis

Data were statistically analyzed and visualized using PAST software version 5.2.2 (Oslo, Norway) and GraphPad Prism version 10.4.2 (San Diego, CA, USA). Lethal concentrations (LC_{30}), along with their 95% confidence limits (CLs) and slope values, were calculated using R software and verified against lower and upper limits using LDP Line software. A normality test was conducted, and descriptive statistics were initially computed. Parametric data were analyzed using one-way analysis of variance (ANOVA), and mean comparisons were performed using Tukey's post hoc test at a significance level of $p<0.05$. Non-parametric data were analyzed using the Kruskal–Wallis test, followed by the Mann–Whitney U test with Bonferroni correction. Spearman's rank correlation was conducted to evaluate the relationship between percent mortality and antifeedant index.

RESULTS AND DISCUSSION

Dose-dependent toxicity

Crude extracts from chili (*C. frutescens*) fruits, madre de cacao (*G. sepium*) leaves, and lemongrass (*C. citratus*) stalks and leaves showed clear dose-dependent toxicity against 3rd instar larvae of *S. frugiperda* (Figure 1). Mortality increased with concentration, with *C. citratus* being the most potent (LC_{30}=51.3 g/L), followed by *C. frutescens* and *G. sepium*. Although their effects were lower than positive control methomyl (LC_{30}=0.00833 g/L), the botanicals displayed gradual but measurable toxicity consistent with prior reports of *C. citratus* essential oils against *S. frugiperda* (Eldesouky et al. 2024). This study also provides the first experimental evidence of sublethal effects from *C. frutescens* and *G. sepium* on *S. frugiperda*. Methomyl, a carbamate insecticide, is highly effective because of its systemic anticholinesterase activity, producing rapid neural overstimulation and mortality (Bird and Drynan 2023). In contrast, these botanicals act more slowly and at higher concentrations.

Feeding deterrence

Feeding bioassays confirmed that the three botanicals also interfere with larval feeding. In dual-choice tests, *C. citratus* caused the strongest feeding deterrence, with larvae consuming only 28.7% of treated leaf discs (Kruskal-Wallis H_1=13.3, $p<0.001$), while *C. frutescens* (H_1=5.67, p=0.018) and *G. sepium* (H_1=4.74, p=0.029) suppressed feeding moderately. However, there was no significant difference among the three botanicals (two-way ANOVA: $F_{2,}$ 57=0.269, p=0.076) (Figure 2). In no-choice tests, both *C. citratus* (31.3% consumption; two-way ANOVA: $F_{4,}$ 96=6.30, p=0.042) and *G. sepium* (34.8%; p=0.023) significantly reduced consumption relative to the negative control, while *C. frutescens* (38.2%; p=0.124) was less effective. Methomyl-treated leaves had the lowest consumption in the no-choice test (18.9%; $p<0.001$), but in the dual-choice test, feeding differences were not significant ($H_1=1.02$, $p=0.312$), likely due to rapid larval death rather than true feeding deterrence.

Antifeedant index values which compares larval consumption of treated versus control leaves (Lewis and van Emden 1986) further distinguished deterrence from toxicity: *G. sepium* recorded the highest mean in the dual-choice assay (49.2%) while the positive control recorded the highest mean in the no-choice test (66.4%) (Figure 3). Mortality rates among botanicals remained low (≤15%) compared to methomyl (30%), confirming that suppression was behavioral rather than lethal. These mortality patterns were further supported by correlation analysis, which showed a weak, non-significant negative relationship ($r=–0.26$, $p=0.75$) between the dual-choice antifeedant index and mortality, and a moderate but also non-significant positive association in the no-choice test ($r=0.4$, $p=0.75$). However, given the small sample size and consequently low statistical power, these correlations should be interpreted with caution.

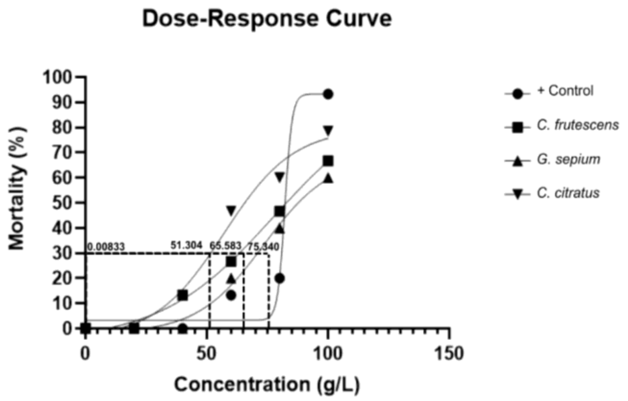

Figure 1. Dose–response mortality of 3rd instar larvae of *Spodoptera frugiperda* exposed to crude extracts of lemongrass (*C. citratus*), chili (*C. frutescens*), and madre de cacao (*G. sepium*), compared with the positive control methomyl. Curves represent fitted probit models, and broken lines show LC_{30} values

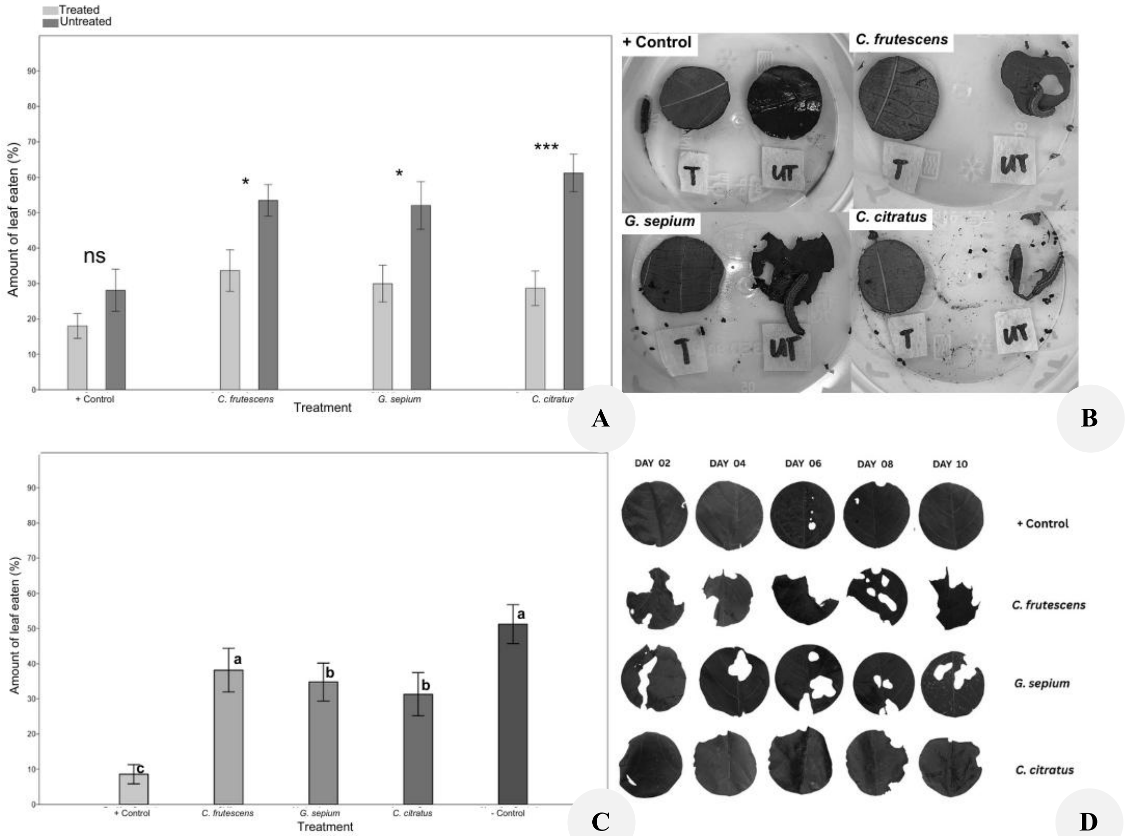

Figure 2. Feeding deterrence of botanical extracts against 3rd instar *Spodoptera frugiperda*. A. Mean percentage of leaf area consumed in a dual-choice assay with LC_{30}-treated and untreated castor leaves and C. No-choice with LC_{30}-treated castor leaves. B. Experimental setup of the dual-choice test and D. Representative feeding activity of larvae on LC_{30}-treated leaves recorded across 10 days, illustrating deterrent effects of botanical extracts compared with controls. Bars show mean ± SEM (n=20). Statistical significance: $p<0.05$(*), $p<0.01$(**), $p<0.001$(***), 'ns': not significant. Treatments sharing the same letter are not significantly different ($p>0.05$)

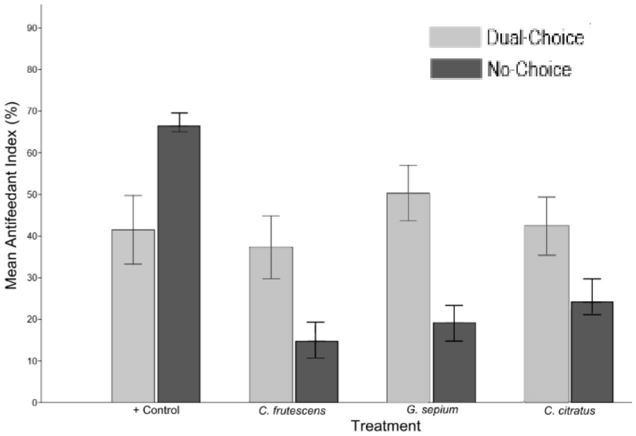

Figure 3. Antifeedant activity of botanical extracts against 3rd instar *Spodoptera frugiperda*. Mean Antifeedant Index (%) calculated from dual-choice and no-choice feeding assays on LC_{30}-treated castor leaves. Bars represent mean ± SEM (n=20). Higher values indicate stronger deterrence

Antifeedants typically act on specific sensory cells and receptors in insects, with associated neurons either preventing initial feeding (deterrent effect), often observed in barrier planting, or reducing further feeding (suppressant effect) as seen in insect sprays, and among the three, *C. citratus* consistently exhibited strong deterrent and suppressant activity in both feeding assays. This outcome resonates with ethnobotanical practices as *C. citratus* is widely used in the Philippines both as a foliar spray and intercrop barrier; its deterrent and suppressant effects observed here validate its field effectiveness (Calumpang et al. 2013), and as effective essential oils and leaf powders have been utilized by local farmers in Nigeria to repel stored-product pests (Folake et al. 2023). *Gliricidia sepium* demonstrated strong deterrence but weaker suppression, suggesting that its role in pest management may be better suited to barrier planting where avoidance is favored. *Gliricidia sepium* has long been planted along rice field margins to reduce tungro virus vectors in the Philippines (Calumpang et al. 2014) and is also associated with higher maize yields in Africa when used as a botanical spray (Kenis et al. 2022). The effectiveness of *C. frutescens* is also evident in Uganda, where it is commonly used to spray crops, illustrating how culturally rooted bio-insecticidal practices are supported by laboratory evidence of feeding deterrence (Tavares et al. 2021). Its widespread use as food, medicine, and bio-insecticide reflects a multifunctional value that goes beyond mere efficacy. Comparable antifeedant efficacy has also been demonstrated under laboratory conditions. For instance, *C. citratus* essential oil shows strong repellency against stored-product pests due to terpenoids such as citral and geranyl acetate (Gvozdenac et al. 2021). Similarly, *G. sepium* and *C. frutescens* extracts have antifeedant effects against closely related species *Spodoptera litura* (Parvathi and Jamil 1999; Movva and Pathipati 2017). These deterrent effects are linked to volatile and bitter-tasting secondary metabolites such as citral in *C. citratus*, capsaicinoids in *C. frutescens*, and coumarins in *G. sepium* that insects detect through olfactory and gustatory cues. Overall, these findings indicate that the three botanicals mainly serve as feeding deterrents with moderate toxicity. Their impacts, although slower, align with farmers' traditional knowledge across different regions, showing that cultural pest management methods are based on practical ecological results.

Development and survival

Prolonged exposure to sublethal concentrations of crude extracts disrupted feeding behavior, growth, and survival of *S. frugiperda*, though effects varied among botanicals.

Developmental parameters

Cymbopogon citratus and *G. sepium* sped up molting, suggesting disruption of normal hormonal regulation. In contrast, *C. frutescens* showed insectistatic (causing increased larval duration) properties, reduced survival to 35%, and caused malformations (Table 1). Prolonged exposure to plant volatiles is known to increase physiological stress and interfere with molting in lepidopterans (Kaur et al. 2023; Idowu and Alabi 2024). Among the three botanicals*, C. citratus* showed the highest survival but was the only one to cause larval deformities, likely through citral-mediated disruption of chitin biosynthesis (Jin et al. 2022). *Capsicum frutescens* insecticidal effects parallels observations in *S. litura*, where phenolic compounds such as vanillic, syringic, chlorogenic, and sinapic acids lead to delayed larval development (Movva and Pathipati 2017); *G. sepium* produced milder effects overall.

Survival rates during the later life stages remained steady, indicating that the larval stage is the most vulnerable to botanicals (Table 2). Studies confirm that botanical effectiveness is highest when used against early folivorous larval stages with chewing mouthparts (Pavela et al. 2025). Disrupting larvae early not only delays their growth but also increases their susceptibility to predators, parasitoids, and botanical pesticide applications, potentially boosting natural biological control. Similar reports show that the larval stage of *S. frugiperda* is highly susceptible to 69 plant-derived extracts, including *Cymbopogon citratus*, which cause mortality, growth suppression, and delayed development (Rioba and Stevenson 2020). For farmers, targeting the larval stage of *S. frugiperda* can lower application frequency, reduce costs, minimize crop losses, and decrease chemical use.

Table 1. Larval duration (days) and survivability (%) of *S. frugiperda* treated with botanical extracts

Treatment	Dose (LC_{30}: g/L)	Duration (days) (Mean ± Sem)	Survival (%)	Malformations (%)
C. frutescens	65.6	7±0.527a	45	0
G. sepium	75.3	4.57±0.327bc	70	0
C. citratus	51.3	4.06±0.213c	80	5
Control (+)	0.00833	6±0.275ab	60	0
Control (-)	0	5.56±0.372ab	90	0

Note: Means (± SEM) with similar letters in the column are not statistically significant

Morphological abnormalities

The botanicals induced prepupal molting failures, malformed pupae, and adults with wing deformities that reduced survival and reproduction. Deformities were most common during the pupal stage (Table 2), when disruption of hormonal regulation and structural reorganization interference led to incomplete development. *Cymbopogon citratus* produced the most malformations overall and was the only extract to induce unique prepupal deformities, highlighting its strong growth-regulating effect. *Capsicum frutescens* caused the highest frequency of pupal malformations and abnormal adult emergence, while *G. sepium* induced fewer but still notable defects. Across its life cycle, *S. frugiperda* experiences stage-specific disruptions from different botanicals: larval feeding deterrence and growth inhibition limit maturity, prepupal deformities caused by *C. citratus* stop pupal formation and metamorphosis, pupal malformations largely induced by *C. frutescens* prevent adult emergence, and adult sublethal effects across treatments reduce longevity, fecundity, and dispersal. Collectively, these abnormalities exert significant ecological impacts that weaken pest populations across generations. Sublethal effects such as delayed growth and deformities, though less immediate than mortality, suppress population growth across generations and strengthen community-based pest management (Figure 4).

Ethnobotanical records across Southeast Asia support the findings of this study, highlighting *Cymbopogon* and *Capsicum* species and *G. sepium* as effective farmer-derived pest control agents. In the Philippines, these plants are traditionally used as insecticides by Ayta, Matigsalug, and Maranao farmers, and similar practices are reported in Indonesia and Vietnam, demonstrating regional relevance (Obico and Ragragio 2014; Dao-Huy et al. 2021; Afrianto et al. 2022; Valdez 2023). Water-based preparations, valued by smallholder farmers for their low cost and ease of use, are comparable to essential oils or ethanol-based extracts reported in prior studies and have significantly affected *S. frugiperda*. Recent laboratory and field studies support these results: *C. citratus* essential oils show strong larvicidal and deterrent effects against *S. frugiperda*, phenolic compounds of *C. frutescens* reduce survival and disrupt larval development, and methanolic extracts of *G. sepium* exhibit antifeedant effects against the closely related *S. litura*, traits that contribute to its effectiveness as an intercrop (Parvathi and Jamil 1999; Movva and Pathipati 2017). These culturally important plants serve dual roles: traditional sources in households and agriculture, and now scientifically proven as effective, affordable, and sustainable pest control agents. By combining traditional knowledge with scientific validation, this study shows that ethnobotanical insecticides are not only effective and environmentally friendly alternatives to synthetic chemicals, but they could also help preserve biodiversity, promote resilience, and support food security across the Philippines and Southeast Asia.

Table 2. Survivability (%) and morphological abnormalities (%) in remaining life stages of *S. frugiperda* treated with botanical extracts

Treatment	**Dose (LC_{30}: g/L)**	**Survival (%)**			**Malformations (%)**		
		Pre-pupae	**Pupae**	**Adults**	**Pre-pupae**	**Pupae**	**Adults**
C. frutescens	65.6	45	35	35	0	28.6	14.3
G. sepium	75.3	70	65	65	0	7.69	7.69
C. citratus	51.3	75	70	70	6.25	14.3	7.14
Control (+)	0.00833	60	55	55	0	9.09	0
Control (-)	0	90	90	90	0	0	0

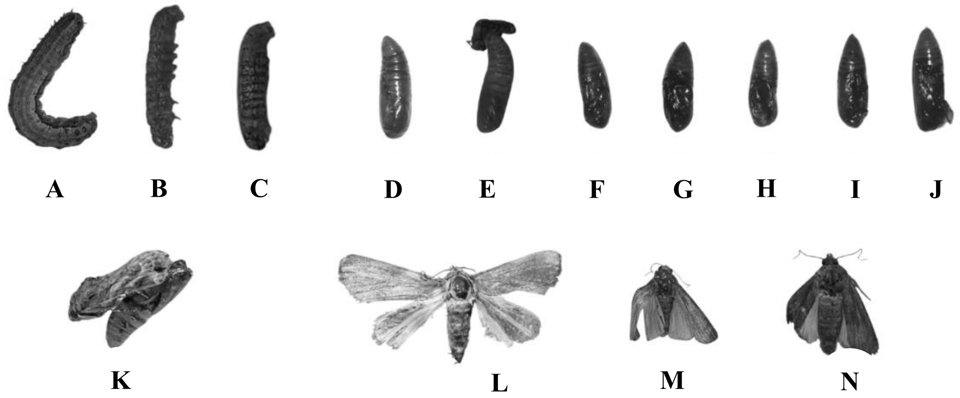

Figure 4. Sublethal effects of botanical treatments on various life stages of the fall armyworm, *Spodoptera frugiperda*. A. Healthy 6th instar larva; B, Darkened, shriveled, and twisted 6th instar larval body with visible prolegs; C. Short, underdeveloped pre-pupa; D. healthy pupa; E. Partially transformed larva with molting failure; F-I. Small, possibly dehydrated or incompletely formed pupae; J. Pupa with a swollen or malformed terminal segment; K. Adult moth that failed to emerge fully and remains attached to the pupal capsule; L. Normal, fully emerged adult; M. Malformed adult with shriveled, undersized wings; and N. Malformed adult with asymmetrical wings, left wing is shorter than the right. Morphological abnormalities are shown for *C. citratus* (B, C, E, J, N), *C. frutescens* (G, H, K), *G. sepium* (I, M), and the positive control, methomyl (F)

Nevertheless, several limitations should be recognized. Laboratory conditions cannot replicate field complexities such as changing temperature, UV degradation, rainfall wash-off, and interactions with natural enemies, which may affect the effectiveness of botanical extracts. Crude extracts can also vary in phytochemical content depending on plant age, season, or growing location, impacting consistency and reproducibility. Potential non-target effects on beneficial insects and soil microbiota were not evaluated and should be addressed in future studies. Moreover, unlike synthetic pesticides that act through rapid toxicity, these plant extracts act more gradually through feeding deterrence, growth disruption, and reduced survival, which suppress pest populations and lower crop damage. These points suggest that the current results are preliminary rather than definitive, but they highlight the long-term potential of botanicals for sustainable crop protection. Future research should focus on field-based validation under farmer-managed conditions, along with phytochemical profiling to identify bioactive compounds, biodiversity, and soil health evaluation. Dose optimization and potential synergistic effects of crude extract combinations, such as lemongrass with chili as a foliar spray or lemongrass with madre de cacao in intercrop systems, should also be explored. Finally, participatory research with farming communities is essential to develop practical, culturally relevant formulations and assess socioeconomic feasibility. Their integration into modern IPM frameworks could further strengthen sustainable pest management strategies. Such approaches will help ensure that botanical insecticides are biologically effective, environmentally safe, and sustainable, while supporting farmers through reduced pesticide costs, improved crop protection, and more resilient income for smallholder households.

ACKNOWLEDGEMENTS

Gratitude is extended to Cyril Tura of Davao Oriental State College of Science and Technology, Mati, Davao Oriental, for providing the *S. frugiperda* culture and for guiding us on its proper handling. Moreover, sincere thanks to the research assistant in the Molecular Ecology and Physiology Laboratory, Jamiel C. Macaraya, for his assistance; to our professors, Dr. Mylah V. Tabelin and Dr. Joey Genevive T. Martinez for their invaluable guidance throughout our special project; and to the Department of Science and Technology – Accelerated Science and Technology Human Resource Development Program (DOST-ASTHRDP) for the scholarship support. Acknowledgement to the support of Mindanao State University–Iligan Institute of Technology (MSU-IIT), the College of Science and Mathematics (CSM), the Department of Biological Sciences (DBS), and the Premier Research Institute of Science and Mathematics (PRISM). Moreover, expression of gratitude to Mr. and Mrs. Labonete for their continuous support. The authors declare no competing financial interests or personal relationships influencing this work. This manuscript is original, unpublished, and not under review elsewhere. The authors take full responsibility for their content.

REFERENCES

Abbott WS. 1925. A method of computing the effectiveness of an insecticide. J Econ Entomol 18: 265-267. DOI: 10.1093/jee/18.2.265a.

Afrianto WF, Putra RP, Aini YS. 2022. Overview of the ethnobotany on the use of plants as potential botanical pesticides in Indonesia. Jurnal Biologi Tropis 22: 220-243. DOI: 10.29303/jbt.v22i1.3266.

Bird L, Drynan L. 2023. Comparison of insecticide toxicity in adult and larval stages of *Spodoptera frugiperda* (JE Smith) and *Helicoverpa armigera* (Hünber) (Lepidoptera: Noctuidae). Crop Prot 166: 106185. DOI: 10.1016/j.cropro.2023.106185.

Calumpang SMF, Bayot RG, Vargas DG, Ebuenga MD, Gonzales PG. 2013. Impact of intercropping lemon grass (*Cymbopogon citratus* Stapf.) on infestation of eggplant fruit and shoot borer (*Leucinodes orbonalis* Guenée) in eggplant (*Solanum melongena* L.). Silliman J 54 (1): 114-130.

Calumpang SMF, Navasero MM, Burgonio GAS, Navasero MV. 2014. Repellency of volatile organic chemicals of kakawate, *Gliricidia sepium* (Jacq.) Walp., to rice green leafhopper, *Nephotettix virescens* (Distant) (Hemiptera: Cicadellidae). Philipp Agric Sci 97 (2): 148-154.

Dao-Huy T, Dao VH, Vu DH, Le DQ, Tran DL. 2021. Application of botanical pesticides in organic agriculture production: Potential and challenges. Vietnam J Sci Technol 59 (6): 679-701. DOI: 10.15625/2525-2518/59/6/15574.

Desneux N, Decourtye A, Delpuech JM. 2007. The sublethal effects of pesticides on beneficial arthropods. Ann Rev Entomol 52: 81-106. DOI: 10.1146/annurev.ento.52.110405.091440.

Ejeta D, Asme A, Asefa A. 2021. Insecticidal effect of ethnobotanical plant extracts against *Anopheles arabiensis* under laboratory conditions. Malar J 20 (1): 466. DOI: 10.1186/s12936-021-04004-6.

Eldesouky SE, Abdou MS, Hassan SM. 2024. The sublethal effects of both essential oils (*Cymbopogon citratus* and *Mentha piperita*) on *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae). Alex Sci Exch J 45 (3): 1-9. DOI: 10.21608/asejaiqjsae.2024.388830.

Folake AO, Matthew O, Adewale AO, Ibrahim MG. 2023. Insecticidal activity of botanicals and their effectiveness in insect and pest control. South Asian J Agric Sci 3 (2): 88-96. DOI: 10.22271/27889289.2023.v3.i2b.95.

Gvozdenac S, Kiprovski B, Aćimović M, Jeremić JS, Cvetković M, Bursić V, Ovuka J. 2021. Repellent activity of *Cymbopogon citratus* essential oil against four major stored product pests: *Plodia interpunctella*, *Sitophilus oryzae*, *Acanthoscelides obtectus*, and *Tribolium castaneum*. Contemp Agric 70 (3-4): 140-148. DOI: 10.2478/contagri-2021-0020.

Idowu O, Alabi O. 2024. Contact toxicity and feeding deterrent activity of *Dennettia tripetala* Bak. and *Jatropha curcas* L. leaf extracts against *Spodoptera frugiperda* JE Smith. J Basic Appl Zool 85 (1): 1-10. DOI: 10.1186/s41936-024-00413-6.

Jin C, Han H, Xie Y, Li B, Zhang Z, Zhang D. 2022. Toxicity, behavioral effects, and chitin structural chemistry of *Reticulitermes flaviceps* exposed to *Cymbopogon citratus* EO and its major constituent citral. Insects 13 (9): 812. DOI: 10.3390/insects13090812.

Kaur N, Singh D, Singh A, Mahajan K, Thakur A, Singh AAR. 2023. Efficacy of botanical pesticides on biology and cellular immune active response of greater wax moth, *Galleria mellonella* Linnaeus. Biopestic Intl 19 (2): 199-206. DOI: 10.59467/bi. 2023.19.199.

Kenis M, Benelli G, Biondi A, Calatayud P, Day R, Desneux N, Harrison RD, Kriticos D, Rwomushana I, Van Den Berg J, Verheggen F, Zhang Y, Agboyi LK, Ahissou RB, Ba MN, Bernal J, Nègre N. 2022. Invasiveness, biology, ecology, and management of the fall armyworm, *Spodoptera frugiperda*. Entomol Gen 43 (2): 187-241. DOI: 10.1127/entomologia/2022/1659.

Kusano E, Poapongsakorn N, Jantarasiri U, Pantakua K, Tran CH, Tar NKA, Kong T, Phimphachanhvongsod VV, Kobori Y. 2025. Government and farmer responses to the fall armyworm outbreak in mainland Southeast Asia. Front Insect Sci 4: 1455585. DOI: 10.3389/finsc.2024.1455585.

Labonete HJP, Jimenez EA, Torres MAJ, Demayo CG. 2025. Ethnobotanical and phytochemical insights on insecticidal plants in the Philippines for sustainable crop protection: a systematic review and network analysis. Intl J Agric Biosci 14 (6): 1206-1230. DOI: 10.47278/journal.ijab/2025.088.

Labonete HJP, Torres MAJ, Llantos OE, Demayo CG. 2024. Biology, distribution, and management of fall armyworm in the Philippines: A PRISMA-guided systematic review and meta-analysis. J Entomol Res 48 (2): 131-138. DOI: 10.5958/0974-4576.2024.00028.6.

Lewis AC, Van Emden HF. 1986. Assays for insect feeding. In: Miller JR, Miller TA (eds.). Insect-Plant Interactions. Springer, New York.

Movva V, Pathipati UR. 2017. Feeding-induced phenol production in *Capsicum annuum* L. influences *Spodoptera litura* F. larval growth and physiology. Arch Insect Biochem Physiol 95 (1). DOI: 10.1002/arch. 21387.

Obico JJ, Ragragio E. 2014. A survey of plants used as repellents against hematophagous insects by the Ayta People of Porac, Pampanga Province, Philippines. Philipp Sci Lett 7 (1): 179-186.

Pavana JK, Deshmukh SS, Mallikarjuna HB, Kalleshwaraswamy CM, Naik TB, Mota-Sanchez D. 2023. Sublethal effects of botanicals on the growth and development of fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae). Curr Sci 125 (1): 52-58. DOI: 10.18520/cs/v125/i1/52-58.

Parvathi K, Jamil K. 1999. Toxic, growth-inhibitory, and antifeedant activity of *Gliricidia sepium* Jacq. Leaf extract against *Dysdercus koenigii* Fabricius, *Achaea janata* Linnaeus, and *Spodoptera litura* Fabricius. Intl J Trop Insect Sci 19 (2-3): 217-222. DOI: 10.1017/s1742758400019500.

Pavela R. 2016. History, presence, and perspective of using plant extracts as commercial botanical insecticides and farm products for protection against insects – a review. Plant Prot Sci 52 (4): 229-241. DOI: 10.17221/31/2016-pps.

Phambala K, Tembo Y, Kasambala T, Kabambe VH, Stevenson PC, Belmain SR. 2020. Bioactivity of common pesticidal plants on fall armyworm larvae (*Spodoptera frugiperda*). Plants 9 (1): 112. DOI: 10.3390/plants9010112.

Rioba NB, Stevenson PC. 2020. Opportunities and scope for botanical extracts and products for the management of fall armyworm (*Spodoptera frugiperda*) for smallholders in Africa. Plants 9 (2): 207. DOI: 10.3390/plants9020207.

Salem SAR, Dahi HF, Abdel-Galil FA, Mahmoud MA. 2023. Efficacy of common synthetic insecticides for management of fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in Egypt. Egypt Acad J Biol Sci F Toxicol 15 (1): 157-170. DOI: 10.21608/eajbsf. 2023.303457.

Tavares WR, Barreto MDC, Seca AML 2021. Aqueous and Ethanolic Plant Extracts as Bio-Insecticides—Establishing a Bridge between Raw Scientific Data and Practical Reality. Plants 10 (5): 920. DOI: 10.3390/plants10050920.

Tura CL, Joshi RC, Aceres LV. 2025. Life history of fall armyworm *Spodoptera frugiperda* (J.E. Smith) on castor, under laboratory conditions. Indian J Entomol Indian J Entomol 88: 525-530. DOI: 10.55446/ije.2025.3093.

Valdez AV. 2023. Indigenous pest control: the case of Meranao farmers in Southern Philippines. J Entomol Zool Stud 11 (4): 1-7. DOI: 10.22271/j.ento.2023.v11.i4a.9208.