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Efficacy of Hydroalcoholic Extracts of *Ricinus communis*, *Azadirachta indica* and *Tephrosia vogelii* for Control of Fall Armyworm (*Spodoptera frugiperda*) in Maize under Fild Condition in Quibala community, Uíge (Angola)

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A B S T R A C T
This field study evaluated the efficacy of hydroalcoholic extracts of *Ricinus communis*, *A. indica* and *T. vogelii* on the control of *Spodoptera frugiperda* (J. E. Smith, 1797) in maize in Quibala, Uíge (Angola) from February to June 2025. A completely randomized design with three replicates per treatment was implemented over a total area of 483 m². Extracts were prepared by maceration using a locally distilled beverage ("capuca" with an ethanol concentration of 48% v/v) and applied by foliar spray to naturally infested maize (cv. Samaru 13). Entomological parameters included number of affected plants, live larvae (LL) and dead larvae (DL); efficacy was calculated using Abbott's equation. One-way ANOVA detected significant differences among treatments ($p < 0.05$); Two-way ANOVA (treatment × week) showed highly significant main effects (treatment and week: $p < 0.001$) and a significant interaction ($p = 0.002$). A multiple regression model using log-transformed LL and DL explained 69.6% of the variance in efficacy (adjusted $R^2 = 0.696$; $F = 119.8$; $p<1.7\times10^{-27}$). *R. communis* produced the fastest initial larval mortality and highest mean efficacy, followed by *T. vogelii*; both were performing comparably to the reference treatment. *A. indica* showed a slower, but sustained effect, whereas the "Kangila" formulation had low efficacy. These results support further development of *R. communis* and *T. vogelii* extracts for smallholder integrated pest management, with further research additional work on formulation and application schedules to improve field persistence.

Keywords: *Spodoptera frugiperda*; plants hydroalcoholic extracts; efficacy; integrated pest management; Angola

Eficácia dos extratos hidroalcoólicos de *Ricinus communis*, *Azadirachta indica* e *Tephrosia vogelii* no controlo da lagarta-do-cartucho (*Spodoptera frugiperda*) no milho em condições de campo na comunidade de Quibala, Uíge (Angola)

R E S U M O
Este estudo de campo avaliou a eficácia dos extratos hidroalcoólicos de *Ricinus communis*, *Azadirachta indica* e *Tephrosia vogelii* no controlo de *Spodoptera frugiperda* (J. E. Smith, 1797) no milho, em Quibala, Uíge (Angola), entre fevereiro e junho de 2025. Foi utilizado um delineamento completamente casualizado com três repetições por tratamento, em uma área total de 483 m². Os extratos foram preparados por maceração usando uma bebida destilada local ("capuca", com teor alcoólico de 48% v/v) e aplicados por pulverização foliar em milho naturalmente infestado (cv. *Samaru 13*). Os parâmetros entomológicos incluíram número de plantas afetadas, larvas vivas (LL) e larvas mortas (DL); a eficácia foi calculada pela equação de Abbott. A ANOVA unidirecional detectou diferenças significativas entre tratamentos ($p<0.05$); a ANOVA bivariada (tratamento × semana) mostrou efeitos principais altamente significativos (tratamento e semana: $p<0.001$) e interação significativa ($p=0.002$). Um modelo de regressão múltipla, usando LL e DL

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transformadas pelo log, explicou 69,6% da variância na eficácia (R^2 ajustado =0.696; F=119.8; p<1.7×10−27). *R. communis* apresentou a mortalidade larvar inicial mais rápida e a maior eficácia média, seguido por *T. vogelii*; ambos tiveram desempenho comparável ao tratamento de referência. *A. indica* mostrou um efeito mais lento, porém sustentado, enquanto a formulação "Kangila" apresentou baixa eficácia. Estes resultados apoiam o desenvolvimento adicional dos extratos de *R. communis* e *T. vogelii* para o manejo integrado de pragas por pequenos agricultores, recomendando-se estudos complementares sobre formulação e esquemas de aplicação para melhorar a persistência em campo.

Palavras-Chaves: *Spodoptera frugiperda*; extratos hidroalcoólicos de plantas; eficácia; manejo integrado de pragas; Angola

Eficacia de los extractos hidroalcohólicos de *Ricinus communis*, *Azadirachta indica* y *Tephrosia vogelii* para el control de la oruga militar del maíz (*Spodoptera frugiperda*) en maíz en condiciones de campo en la comunidad de Quibala, Uíge (Angola)

R E S U M E N

Este estudio de campo evaluó la eficacia de los extractos hidroalcohólicos de *Ricinus communis*, *Azadirachta indica* y *Tephrosia vogelii* en el control de *Spodoptera frugiperda* (J. E. Smith, 1797) en maíz en Quibala, Uíge (Angola) entre febrero y junio de 2025. Se empleó un diseño completamente al azar con tres repeticiones por tratamiento en una superficie total de 483 m². Los extractos se prepararon por maceración utilizando una bebida destilada local ("capuca", con concentración de etanol de 48% v/v) y se aplicaron por pulverización foliar sobre maíz naturalmente infestado (cv. *Samaru 13*). Los parámetros entomológicos incluyeron número de plantas afectadas, larvas vivas (LL) y larvas muertas (DL); la eficacia se calculó mediante la ecuación de Abbott. La ANOVA unidireccional detectó diferencias significativas entre tratamientos (p<0.05); la ANOVA de dos vías (tratamiento × semana) mostró efectos principales altamente significativos (tratamiento y semana: p<0.001) y una interacción significativa (p=0.002). Un modelo de regresión múltiple, usando LL y DL transformadas por logaritmo, explicó el 69,6% de la varianza en la eficacia (R^2 ajustado =0.696; F=119.8; p<1.7×10−27). *R. communis* produjo la mortalidad larvaria inicial más rápida y la mayor eficacia media, seguido por *T. vogelii*; ambos mostraron un rendimiento comparable al tratamiento de referencia. *A. indica* presentó un efecto más lento pero sostenido, mientras que la formulación "Kangila" mostró baja eficacia. Estos resultados respaldan el desarrollo adicional de los extractos de *R. communis* y *T. vogelii* para el manejo integrado de plagas en pequeños agricultores, recomendando investigaciones complementarias sobre formulación y esquemas de aplicación para mejorar la persistencia en campo.

Palabras clave: Spodoptera frugiperda; extractos hidroalcohólicos de plantas; eficacia; manejo integrado de plagas; Angola.

1. Introduction

Agricultural productivity has been driven by the development of high-yielding varieties, improved cultivation practices, fertilizers use, and other technichnological advances. However, increase production often leads to greater susceptibility to pest attacks, resulting in significant losses. Without the use of pesticides, these losses could reach up to 70% of yield, highlighting the importance of pest control strategy for food security (Fan et al., 2012). Maize is a staple crop widely used for both human and animal consumption and represents an important raw material for industrial applications. However, pest infestations can substantially reduce yield and grain quality, leading to significant economic losses. Among the most important pests of maize, the fall armyworm (*Spodoptera frugiperda*), stands out as the major threat (Mampasi and Munanga, 2025), which under favorable conditions, can rapidly increase in population, causing defoliating and ear damage, thereby compromising grain production (Farias et al. 2001; Duveiller et al. 2007).

In *Spodoptera frugiperda* is one of the principal pests of maize across Africa, causing substantial yield losses and threatening food security in farming communities, particularly in tropical regions (Goergen et al., 2016; Togola et al., 2025). Its high reproductive rate, mobility, and capacity to develop resistance to synthetic insecticides make it an increasing challenge for conventional pest management (Day et al., 2017; Hruska, 2019)**.** The fall armyworm, *Spodoptera frugiperda* (order Lepidoptera and family Noctuidae), is one of the most destructive pests in tropical regions due to its wide geographic distribution and year-round occurrence (Adhikari et al. 2020; Jing et al. 2021; Mendesil et al. 2023; Mengesha et al. 2023). Globally, it is considered one of the main insect pests of maize crops (Mendes et al. 2011; Sisay et al. 2019; Tanyi et al. 2020).

The fall armyworm (*Spodoptera frugiperda*) is considered a serious invasive pest that posing a major threat to global food security (Day et al. 2017; EFSA, 2017; Rwomushana, 2019; Njuguna, 2021; Kenis et al. 2023). This species can completely devastate cereal crops in an entire country. The use of plant extracts for pest control offers several advantages, including: i) reduced production costs, ii) lower environmental impact and non-target effects, and iii) reduced dependence on synthetic insecticides. The use of plant extracts for controlling fall armyworm has been the subject of several studies, with promising results, however, the identification of active compounds and standardization remain limited. Therefore, several plant species have proven to be effective pesticides in the management of the fall armyworm (Rioba and Stevenson, 2020; Phambala et al. 2020; Tulashie et al. 2021; Henangamage et al. 2023).

In this context, plant-derived biopesticides emerge as promising ecological alternatives due to their lower environmental toxicity and accessibility to smallholder farmers. Several plants with documented ethnobotanical uses including *A. indica*, *T. vogelii* and *R. communis* contain bioactive compounds with lethal or repellent effects against insect pests, including lepidopteran larvae (Miresmailli and Isman, 2014; Isman, 2016). Compounds such as azadirachtin, rotenone and ricin have been reported to be effective against early larval stages and may partially or completely substitute synthetic inputs in sustainable agricultural systems (Chowdhury et al., 2024; Corrêa and Salgado, 2011).

The use of these extracts is particularly relevant in communities such as Quibala, Uíge (Angola), where access to commercial phytosanitary products is limited and farming practices rely heavily on local resources (Lengai et al., 2022). Scientific evaluation of locally available plant extracts can provide sustainable, context-adapted pest management solutions that support agricultural sovereignty and phytosanitary resilience (Isman 2016; Valicente, 2020).To support safe and effective adoption, field validation of extract performance is required. This includes statistical evaluation of comparative efficacy against conventional treatments and temporal analysis of mortality dynamics (Montgomery, 2017; Cardoso and Viana, 2011). Modeling tools such as multiple regression and principal component analysis (PCA) are recommended to interpret the complex effects of biopesticides under variable field conditions (Azad et al., 2025; Jolliffe and Cadima, 2016).

Botanical insecticides can be defined as products derived from plant secondary metabolites of plants, exhibiting various effects on harmful insects. They can be found in the form of essential oils, plant extracts, or both. Before the success of synthetic insecticides in the 1940s, botanical insecticides were widely used to protect crops and stored products against pests. However, synthetic insecticides, with advantages in terms of effectiveness, speed, ease of use, and low cost, led to the decline in use, especially in industrialized countries (Padial, 2025). This study aimed to evaluate the efficacy of hydroalcoholic extracts of *R. communis*, *A. indica* and *T. vogelii* against *Spodoptera frugiperda* in maize under field conditions in Quibala community.

2. Material and Methods

2.1 Location, period and experiment design

The experiment was conducted from February to June 2025 in Quibala village, Municipality of Uíge, Uíge Province (Fig. 1), Angola, an area characterised by a tropical, rain-dominated climate with a clearly defined dry season.

Figure 1 - Quibala village, Municipality of Uíge, Uíge Province
Figura 1 - Quibala village, Municipality of Uíge, Uíge Province

Source: Elaborado pelos próprios autores (2025)
Fonte: Source: Elaborated by the authors (2025)

The study site (φ = 7°47’38.838” S; λ = 15°0’47.164 E) is largely covered by herbaceous vegetation, notably *Imperata cylindrica, Smilax spp., Pteridium aquilinum ssp. africanum, Sarcocephalus latifolius and Chromoleuma odorata*. Soils are predominantly sandy loam with pH values near 5.5–6.0. Average temperatures hover around 23 °C during the rainy months and about 21 °C in the dry season, while relative humidity typically falls from 85–90% in the wet season to 70–75% in the dry season. Climatic and pedological details follow the datasets reported by Lautenschläger et al. (2014), Carvalho and Halecki (2021) and INAMET (2025). A completely randomized design was used with three replicates per treatment. Each treatment was implemented in plots of 25.08 m^2 on a total area of 483 m^2. Trials were conducted under field conditions using maize (*Zea mays* L.) variety Samaru 13 naturally infested with *Spodoptera frugiperda*).

2.2 Preparation of extracts

Plant extracts were prepared by maceration following adapted procedures from Lapornik et al. (2005), Albuquerque et al. (2017) and Costa et al. (2019). Leaves of the selected plant species (*R. communis*, *A. indica* and *T. vogelii*) were collected in the field, rinsed with running water and shade-dried without overlap to preserve bioactive compounds. The solvent used was “capuca,” a traditional Angolan alcoholic beverage typically produced by artisanal distillation of sugarcane or fermented fruits (e.g., banana or pineapple). In this study, the *capuca* was derived from sugarcane distillation. For treatment T0, no phytochemical active was applied. For the reference treatment, a synthetic insecticide (commertial name: Kangila) was applied, containing emamectin benzoate 12g/L and imidacloprid 50g/L as active ingredients.

2.3 Determination of ethanol concentration

The ethanol concentration of the *capuca* was determined using the pycnometer method (Rosa et al., 2019; Santos Junior et al., 2020 and Ponte et al., 2022) using an analytical balance (Marte AW-220). After weighing the empty pycnometer, the balance was tared, and the test solution was added, ensuring that no air bubbles adhering to the pycnometer surface; and the temperature was maintained constant during measurements. Measurements were performed in triplicate, and density was calculated as follows:

$$(\mathrm{P}) = \left(\frac{M_2 - M_1}{M_0 - M_1}\right) * 100$$

where: M_0 = mass of the pycnometer filled with water; M_1 = mass of the empty pycnometer; M_2 = mass of the pycnometer filled with the test solution. The sample presented a mean density of 924.869 $kg \cdot m^{-3}$ (0.924869 $g \cdot mL^{-1}$) at 25 °C. After correction to 20 °C, this value corresponded to approximately 48% v/v of ethanol, based on standard alcoholometric tables.

2.4 Extract preparation protocol

The leaves were crushed to obtain 500 g of plant material using a RAF Enjyment Goodlife blender and weighed on an ADITAN electronic scale. Maceration was carried out in a 1.5 L container containing 500 mL of *capuca*, the mixture was left to stand for 24 hours, after which it was stirred, filtered, transferred to a 10 L backpack sprayer for field application, and added 8 L of water, following a procedure similar procedure to. that described by Langa, (2025).

2.5 Application of extracts and entomological assessments

The extracts were applied by foliar spray to maize naturally infested with *Spodoptera frugiperda* (J. E. Smith, 1797). Entomological parameters included the number of affected plants, live larvae (LL) and dead larvae (DL). Biopesticide efficacy was calculated using Abbott's equation to adjust observed mortality for background mortality in control plots (El-Saghier et al. 2023), following the procedures described by (Oliveira 2014) and (Massimbe et al. 2023).

Efficacy (E)=Mt−Mc100−Mc×100

$$\text{Efficiency } (\mathrm{E}) = \left(\frac{Mt - Mc}{100 - Mc}\right) * 100$$

where: Mt = mortality observed in treated plots;
Mc = mortality observed in control plots.

2.6 Estatistical analysis

Statistical analyses were performed in RStudio (v. 4.3.1). One way ANOVA was applied followed by Tukey's HSD test to identify significant differences among treatments ($\alpha = 0.05$). Extract efficacy was modeled using multiple linear regression, with logarithmic transformation of count variables (live and dead larvae) to meet normality and homoscedasticity assumptions. Two-way ANOVA (treatment × time/week) was conducted to evaluate main and interaction effects. Principal Component Analysis (PCA) was used to explore relationships among entomological variables and efficacy, revealing functional groupings among tested extracts.

3. Results and Discussion

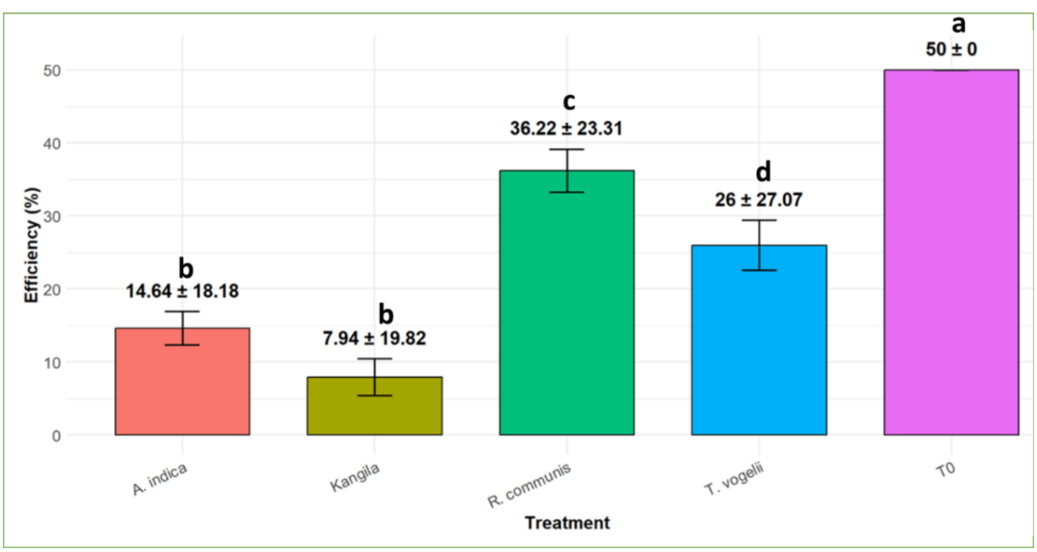
3.1 Entomological performance of natural extracts

The analysis shown in Figure 1 reveals clear and statistically significant differences in the insecticide activity of the botanical treatments against *Spodoptera frugiperda*. *R. communis* exhibited the highest efficacy (36.22 ± 23.31%), followed by *T. vogelii* (26.00 ± 27.07%); both treatments were not significantly different from the reference treatment (50.00 ± 0.00%) according to Tukey's HSD post-hoc test (one-way ANOVA, $p<0.05$). Treatments based on *A. indica* (14.64 ± 18.18%) and Kangla (7.94 ± 19.82%) performed less effectively and did not differ significantly from each other under the experimental conditions.

The variability in efficacy likely reflects species-specific phytochemical profiles and differences in the concentration and interactions of bioactive compounds. Secondary metabolites such as alkaloids, terpenoids, flavonoids and phenolics may act through multiple mechanisms—direct toxicity, feeding deterrence, and disruption of larval development—accounting for the observed differential responses.

The relatively strong performance of *R. communis* highlights its potential as a source of bioactive compounds for botanical pest-management alternatives, while the experimental variability underscores the need for phytochemical characterization, formulation standardization and field validation. These results are consistent with previous findings on the activity of plant-derived compounds against tropical lepidopterans pests (Saeidi et al. 2019).

Figure 1: Comparison of mean efficacies (%) of treatments against S. frugiperda, with groupings from Tukey's HSD test indicating statistically distinct treatments at α = 0.05. Treatments included extracts of *A. indica*, Kangila, *R. communis*, *T. vogelii* and the reference treatment (T_0). Groups sharing the same letter do not differ significantly.
Figura 1: Comparação das eficácias médias (%) dos tratamentos contra *S. frugiperda*, com agrupamentos do teste de Tukey indicando tratamentos estatisticamente distintos a α = 0,05. Os tratamentos incluíram extratos de *A. indica*, Kangila, *R. communis*, *T. vogelii* e o tratamento de referência T_0. Grupos que partilham a mesma letra não diferem significativamente.



Source: Elaborado pelos próprios autores (2025)
Fonte: Source: Elaborated by the authors (2025)

Previous studies he have shown that combining conventional insecticides with botanical compounds presents lethal effects, thereby restoring susceptibility to synthetic insecticides (Ngegba et al., 2022). In addition, these mixtures have been shown to induce sublethal effects, with a negative impact on the sense of smell of adults and on the leaf consumption of the caterpillar. However, using the same backpack sprayer for both chemical pesticides and biopesticides have led to cross-contamination, consequently, reduce the effectiveness of biopesticides due to the presence of chemical residues (Kinyanjui et al. 2025).

Aqueous extract of castor bean (*R. communis*) leaves has been reported to be effective against a wide range of pests, such as ants, termites, mites, caterpillars, mollusks, lice and fleas, as well as fungi and viruses that cause diseases in agriculture. Consistent with these findings, the present results indicate that, under the conditions in which these experiments were carried out, extracts of castor bean (*R. communis* L.) showed a strong inhibitory effect on the survival of fall armyworm caterpillars (Peron and Ferreira 2012).

In the study conducted by Mukanga et al. (2022) the leaf extract of *R. communis* showed superior performance compared to other plant extracts. In the laboratory bioassay, the extracts caused larval mortality rates 27-60% higher than those observed in the untreated control group within 72 hours. In field trials, the leaf extracts significantly reduced infestation rates by 21.7-33.3% compared to the untreated control and reduced the number of larvae per plant by 44-58%. Neem extract is obtained from the seeds of *A. indica*, (*Meliaceae)* a specie that grows in tropical and subtropical regions worldwide. This plant, of Asian origin, is considered one of the most important insecticidal plants in the world. It contains several biological active compounds, the important being azadirachtin. Azadirachtin is toxic to insects, exhibits repellent properties and inhibits feeding and growth. Despite this role as a feeding inhibitor, the mode of action of azadirachtin is not yet fully understood. In general, it is believed to blocks impulses from receptors responsive to phagostimulants and/or stimulates cells involved in feeding inhibition (Rodrigues 2022).

According to Prasoona (2020), the effectiveness of botanical extracts is maximized when they are combined. In that study, interactions between botanical extracts and solvents, significantly enhanced antifeeding activity after 24 hours of application. Neem seed extract combined with ethyl acetate showed the highest increase (60.95%), followed by methanol (58.8%). Similar effects were observed from *Lantana* leaf extract with ethyl acetate (58.8%). Other solvent-extract combinations, including dichloromethane and hexane, also resulted in substantial increases in antifeedant activity (55.9%-56.42%).

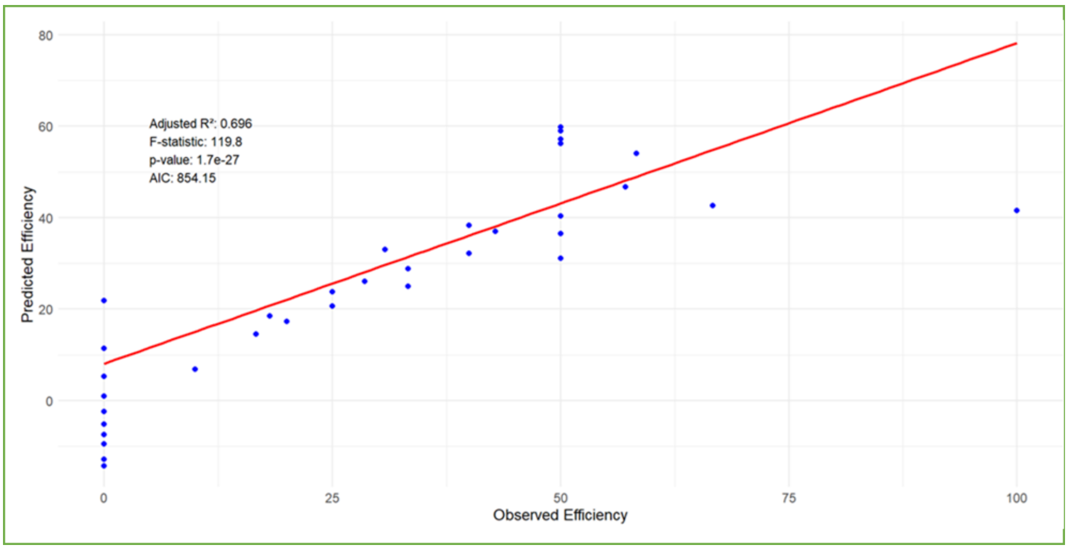
Adeoye, (2021), demonstrated that higher doses of *T. vogelii* and *H. suaveolens* resulted in greater effect on beetle mortality, toxicity, and repellency, as well as less weight loss and seed damage, with mortality rates reaching up to 52% when using ethanolic extract. The ethanolic extract also showed higher toxic ityeffect with LC_{50} of 11.12% after 7 days of exposure and an LD_{50} of 0.33 ml per 10 g of maize kernels after 7 days of exposure. The ethanolic extract of *T. vogelii* was more repellent than aqueous extract of the same plant or and other tested extracts, regardless of the extraction method.

3.2 Statistical validation of efficacy via multiple regression

The relationship between observed and predicted efficacy indicates a satisfactory fit of the statistical model, with a clear positive linear trend between experimental and estimated values (Figure 2). Multiple regression analysis was used to model treatment efficacy as a function of entomological variables (LL = live larvae; DL = dead larvae). Because count data were skewed, both variables were log-transformed [log(LL), log(DL)] to satisfy model assumptions (Montgomery, 2017). The regression model explained approximately 69.6% of the variance in observed efficacy (adjusted R2=0.696; F=119.8; $p=1.7\times10{-}27$), with an AIC of 854.15, indicating a good balance between fit and model complexity (Figure 2). This modelling approach is consistent with methods used in agronomic entomology (Li et al. 2025; Farias et al. 2001).

Despite the overall strong performance, the dispersion of points around the regression line—particularly at lower efficacy levels—suggests that additional factors influence the insecticidal response, such as variation in extract chemical composition, differences in active compound concentrations, and interactions among bioactive constituents. These sources of variability point to the need for complementary analyses, including residual diagnostics, independent validation, and the incorporation of phytochemical and environmental covariates, to improve predictive robustness and field applicability.

Figure 2: Relationship between observed efficacy and efficacy predicted by the multiple regression model based on log(LL) and log(DL).
Figure 3: Relação entre a eficácia observada e a eficácia prevista pelo modelo de regressão múltipla baseado em log(LL) e log(DL).



Source: Elaborado pelos próprios autores (2026)
Fonte: Source: Elaborated by the authors (2026)

The negative association between log(LL) and efficacy indicates that higher larval survival is associated with lower treatment performance, whereas the positive association with log(DL) confirms mortality as a direct efficacy indicator. These patterns align with the bioactivity principles described by Isman (2016) and empirical results reported by Martínez et al. (2021).

Botanical compounds, such as plant essential oils, can serve as alternative to synthetic insecticides as they are considered toxic to pest insects, have low toxicity to mammals, and are generally compatible with biological control programs. Studies report that essential oils are selective to beneficial arthropods, however, exceptions may occur, which requires specific evaluation of their effects on natural enemies (Lima 2020).

Botanical substances offer several advantages: most are low-cost and accessible to farmer; some are highly toxic to pests but do not resist in the environment and decompose rapidly; and most are not toxic to mammals. Plant-derived oils with insecticidal potential are gaining increasing attention in the pesticide industry, leading to reduce productivity and crop quality (Okwute 2012).

Currently, biopesticides are preferred over synthetic pesticides because they are less harmful to the environment. Their effectiveness depends on proper timing and appropriate formulation. Therefore, biopesticides for pest control are developed for various crops because they offer benefits such as lower toxicity, affecting primarly target pest and closely related organisms, effectiveness in small quantities, rapid decomposition, residual traces in food, and low pollution compared to synthetic pesticides (Soyel et al. 2023).

The use of biopesticides leads to a reduction in synthetic pesticides that are dangerous to human and environmental health. The use of plants such as neem (*A. indica*), pepper (*Capsicum annuum*), garlic (*Allium sativum*), moringa (*Moringa oleifera*), clove basil (*Ocimum gratissimum*), chinaberry (*Melia azedarach*), and vernonia (*Vernonia amygdalina*) has been implemented to control various insect pests from families such as *Hemiptera*, *Lepidoptera*, *Thysanoptera*, *Coleoptera*, and *Diptera*, thus enriching agricultural practices, promoting food security, and ensuring agricultural sustainability (Parajuli et al. 2022).

Different studies, such as those by Nemeyimana et al., (2023), have shown that the composition of sustainable bioactive phytochemicals present in plants are active against a wide range of pests, including worms, arthropods, and mites, among others. Various groups of phytochemicals present in these plants, such as alkaloids, saponins, terpenoids, tannins, glycosides, carbohydrates, phytosterols, carotenoids, anthocyanins, phenols, and lignans, have been studied and found in different parts of the plants, including roots, bark, and leaves (Nwozo et al., 2023).

These phytochemicals have varying pesticidal effects, potentially causing respiratory blockage, anti-feeding and anti-oviposition action, and even interruption of metamorphosis cycles with anti-molting properties, further stimulating hormonal imbalances that lead to physiological dysfunctions, causing cuticle disruption, impired mobility and feeding inhibition (Ashamo et al., 2022). According to Rioba and Stevenson (2020), among the different effects on *S. frugiperda*, *R. communis* exhibits actions such as insecticidal and insectistatic, larvicidal, and growth inhibition.

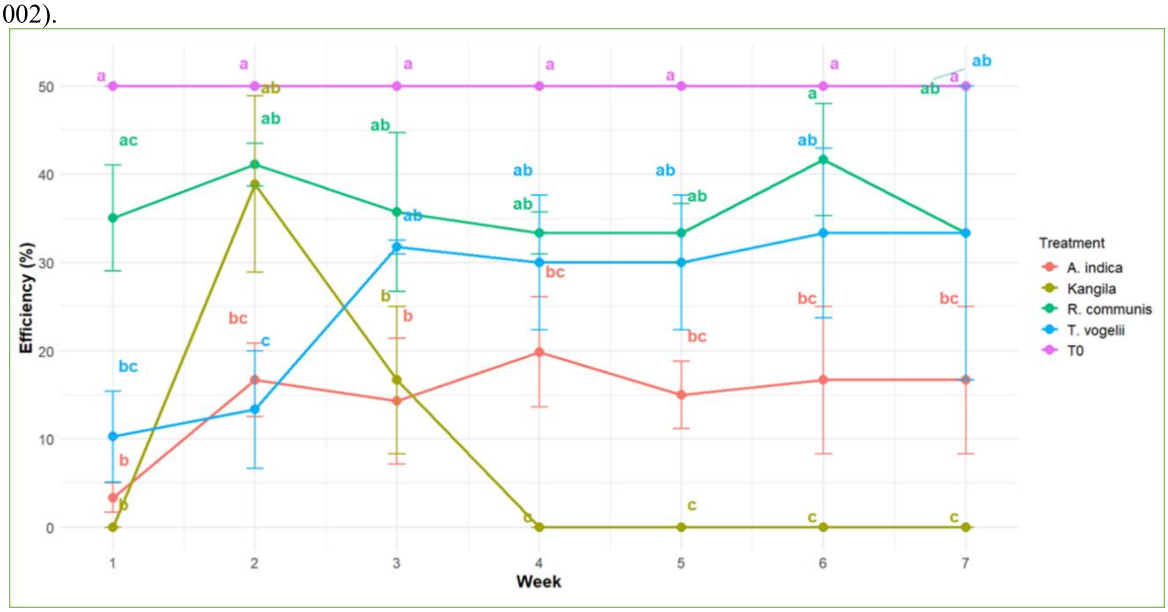
In the study conducted by Prasoona (2020), it was concluded that neem almond extract had greater antifeedant activity against *S. frugiperda* larvae in the third instar when obtained by extraction with ethyl acetate or 1% methanol and was also compared to the effect caused by 1% lantana leaf extract obtained with ethyl acetate. The model's predictive capacity suggests practical applicability for monitoring programs, enabling technicians and farmers to estimate extract efficacy from simple field counts, consistent with evidence based on decision frameworks in entomology (Kiobia et al. 2023).

3.3 Temporal dynamics of efficacy — Two-way ANOVA

Two-way ANOVA (treatment × week) was used to assess temporal dynamics in efficacy; both main effects (treatment and week) were highly significant ($p<0.001$) and the treatment × week interaction was also significant ($p=0.002$), indicating that treatment performance changed over time (Figure 3). Temporal variation revealed distinct response trajectories among the botanical extracts. *R. communis* produced a rapid and pronounced initial suppression of *Spodoptera frugiperda*, followed by a progressive decline in efficacy over the monitoring period, consistent with a strong short-term toxic action but limited persistence of its active constituents under our experimental conditions. By contrast, *T. vogelii* and *A. indica* showed a gradual increase in efficacy during the first weeks and then stabilized at consistently high levels, a pattern that may reflect delayed bioactivity, cumulative effects, or sustained residual action due to the persistence and slow release of secondary metabolites. The Kangila treatment maintained low efficacy throughout the assessment, indicating limited potential for long-term control in the tested conditions.

The untreated control (T_0) provided a baseline for natural pest dynamics and allowed us to quantify the relative performance of each botanical over time. Taken together, these results point to meaningful differences in persistence, mode of action and stability among plant-derived treatments and reinforce the need to evaluate both immediate and residual effects when selecting botanical alternatives for sustainable pest management; they also suggest that formulation and timing will be critical to translate promising short-term toxicity into effective field strategies.

Figure 4: Weekly efficacy (%) of treatments against Spodoptera frugiperda (J. E. Smith, 1797). Mean ± SE; letters indicate Tukey HSD groupings (α = 0.05) — treatments sharing the same letter do not differ significantly within that week. Two-way ANOVA: treatment ($p < 0.001$), week ($p < 0.001$), treatment × week ($p = 0.002$).
Figura 3: Eficácia semanal (%) dos tratamentos contra *Spodoptera frugiperda* (J. E. Smith, 1797). Média ± SE; letras indicam agrupamentos do teste HSD de Tukey (α=0.05) — tratamentos que partilham a mesma letra não diferem significativamente nessa semana. ANOVA de duas vias**:** tratamento ($p<0.001$), semana ($p<0.001$), tratamento × semana ($p=0.002$).



Source: Elaborado pelos próprios autores (2025)
Fonte: Source: Elaborated by the authors (2025)

The application of the hydroalcoholic extract of *R. communis* initially showed a rapid and strong effect in the first two weeks, subsequently a progressive decline in its effectiveness was observed until its total loss. This evolution suggests acute toxicity with limited persistence. Regarding the extracts of *T. vogelii* and *A. indica*, a gradual increase in effectiveness was observed during the first weeks, and subsequently, stabilization was observed when high levels were applied, indicating cumulative or even residual activity of these extracts. The treatment where the commercial insecticide (Kangila) was applied showed consistently low effectiveness throughout the evaluation period of the effects of the extracts studied. Concerning the reference treatment (T_0), this served as an external comparison parameter during the evaluation period.

These profiles suggest differing modes of action and persistence among the tested extracts. The rapid but short-lived effect of *R. communis* may reflect the presence of volatile or labile compounds, requiring reapplication or formulation improvements to enhance field persistence. A similar trend was reported by Isman (2016). The delayed but sustained action of *T. vogelii* and *A. indica* may be attributable to lower volatility, and to more stable active constituents (e.g., rotenone, azadirachtin) which confer residual activity as also repported by Miresmailli and Isman (2014). The low efficacy of the Kangila treatment may result from low concentration of active compounds, suboptimal extraction, or low affinity to the target pest (Corrêa and Salgado 2011).

In contrast to the present study, Mukanga et al. (2022) repported a relatively slow rate of larval mortality caused by crude aqueous leaf extracts, which may have resulted in significant leaf damage in treated maize between successive applications, compared to crop treated with a synthetic insecticide. These authors further suggested that, although the plant extracts were effective in reducing leaf damage caused by the fall armyworm, they were less effective than treatments involving synthetic insecticide.

Mkindi (2020), in a study of productivity treated with *T. vogelii*, and *T. diversifolia*, reported that treated plants exibited higher productivity compared to those treated with synthetic pesticides. Mukanga et al. (2022) also reported that although there was no major difference between the plant extracts, their efficacy increased with the number of applications and that the synthetic insecticide showed greater efficacy than plant extracts.

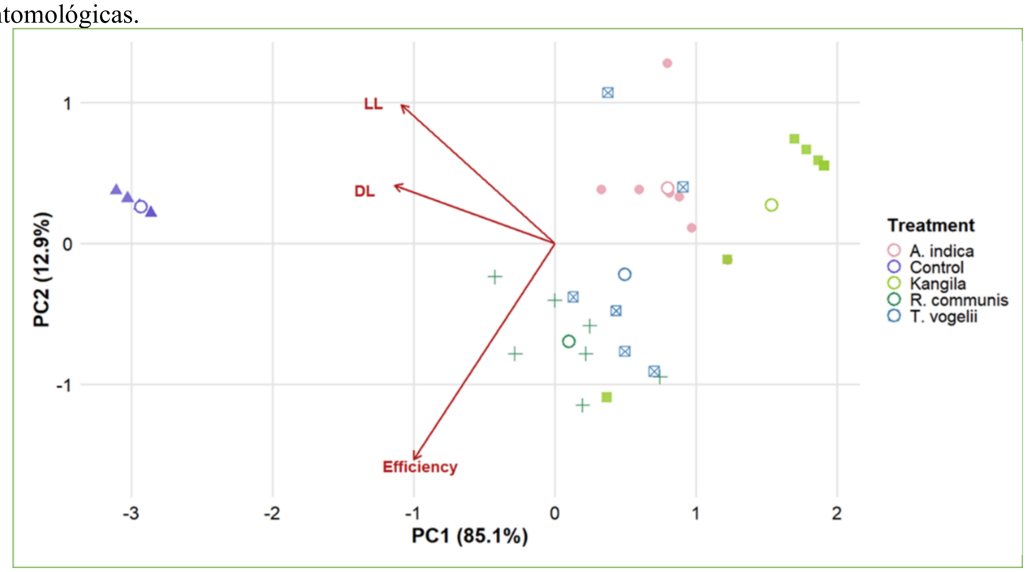
Ahmed et al. 2022) reported that the combination of extracts of *Withania somnifera*, *Sophora mollis*, and *Rhazia stricta* resulted in 29.3% mortality of the fall armyworm, whereas individual treatments resulted in lower larval mortality. The combination of the synthetic insecticide chlorpyrifos with extracts resulted in an observed mortality of 40.0%. Ahmed et al. (2023), reported that larval mortality increased with increasing conidia concentration and exposure time. All tested concentrations of the *B. bassiana* and *M. anisopliae* isolates significantly increased larval mortality from day 3 to 10. A similar trend was observed for *M. anisopliae*, reaching maximum larval mortality values of 76% and 70% of *S. frugiperda* for *B. bassiana* and *M. anisopliae*, respectively, compared to day 1 and lower concentrations.

3.4 Multivariate structure of biological responses (PCA)

The PCA integrating LL (live larvae), DL (dead larvae) and Efficiency showed that the first two components captured the vast majority of the variation (PC1 = 85.1%; PC2 = 12.9%; cumulative 98%), indicating effective dimensionality reduction and a robust ordination. The biplot (Figure 4) reveals a clear structure: R. communis and T. vogelii cluster close to the *Efficiency* vector, indicating a strong positive association with high insecticidal performance. By contrast, Kangila and the untreated control (T_0) align with the *LL* vector, reflecting higher larval survival and correspondingly lower efficacy. *A. indica* occupies an intermediate position, partially overlapping with the other treatments and indicating a mixed response profile.

Point dispersion is informative: *R. communis* shows greater spread around its centroid, consistent with higher within-treatment variability, whereas *T. vogelii* is more tightly clustered, suggesting more consistent performance across replicates. The *Efficiency* vector is positively associated with *DL* and opposed to *LL*, confirming that the ordination captures the expected antagonism between larval survival and treatment effectiveness. These multivariate patterns are summarized in Figure 4 and provide a concise picture of how treatments differ in their biological outcomes.

Figure 5: Principal component analysis (PCA) showing the multivariate distribution of treatments and entomological variables.
Figura 4: Análise de componentes principais (PCA) mostrando a distribuição multivariada dos tratamentos e das variáveis entomológicas.



Projection of treatments and variables (efficacy, DL — dead larvae; LL — live larvae) onto the first two principal components. Vector arrows indicate the direction and strength of variable correlations between variables and components; PC1 = 85.1% and PC2 = 12.9% (cumulative 98%). *R. communis* and *T. vogelii* are positively associated with high efficacy, whereas Kangila and the control are associated with greater larval survival (low efficacy).
Projeção dos tratamentos e das variáveis (eficácia; **DL** — larvas mortas; **LL** — larvas vivas) nos dois primeiros componentes principais. Setas vetoriais indicam a direção e a intensidade das correlações entre variáveis e componentes; PC1 = 85.1% and PC2 = 12.9% (cumulative 98%). *R. communis* e *T. vogelii* estão positivamente associados à alta eficácia, enquanto Kangila e o controlo estão associados a maior sobrevivência larvar (baixa eficácia).

Source: Elaborado pelos próprios autores (2025)
Fonte: Source: Elaborated by the authors (2025)

The proximity of high-efficacy treatments to the efficacy vector is plausibly explained by bioactive secondary metabolites (terpenoids, flavonoids, phenolics) that affect insect mortality and behaviour (Pavela & Benelli, 2016; Isman, 2020; Qie et al., 2022). The larger dispersion for *R. communis* likely reflects heterogeneity in crude-extract composition or concentration among batches, a source of variability commonly reported for botanical insecticides (Miresmailli & Isman, 2013; Jolliffe and Cadima, 2016).

Together, these observations indicate that botanical treatments elicit complex, multidimensional responses and point to priorities for follow-up work — targeted phytochemical profiling, standardization of extract preparation, and field validation — to translate the PCA patterns (Figure 4) into robust pest-management recommendations. Overall, *R. communis* and *T. vogelii* emerged as promising candidates for further development and formulation, whereas Kangila and the control showed limited practical potential without further optimization.

4. Conclusion

This study provides robust experimental and statistical evidence that selected plant extracts can serve as sustainable alternatives for controlling *Spodoptera frugiperda* in tropical maize. One-way ANOVA detected significant differences among treatments ($p < 0.05$), and two-way ANOVA (treatment × week) showed highly significant main effects for treatment and week ($p < 0.001$) with a significant interaction ($p = 0.002$), indicating temporal variation in treatment performance. *R. communis* (36.22 ± 23.31%) and *T. vogelii* (26.00 ± 27.07%) delivered the highest mean efficacies and clustered close to the efficacy vector in the PCA (PC1 = 85.1%, PC2 = 12.9%; cumulative = 98.0%), whereas the untreated control (T_0; no extract) and Kangila aligned with the LL vector. A multiple regression using log-transformed LL and DL explained 69.6% of the variance in efficacy (adjusted R2 = 0.696; F = 119.8; $p < 1.7\times10^{-27}$), confirming that simple field counts are strong predictors of performance. These findings support the integration of selected botanical extracts into community-based integrated pest management (IPM) programs and highlight the need for further research on formulation and application optimization under smallholder farming conditions.

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6. References

Isman, M. B. (2006). Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. **Annual Review of Entomology**, 51, 45–66. https://doi.org/10.1146/annurev.ento.51.110104.151146

Adeoye, A. A. (2021). Bioactivities of *Hyptis suaveolens* and *Tephrosia vogelii* leaves extracts on *Prostephanus truncatus* (Master's thesis). Department of Crop Production, Kwara State University, Malete, Kwara State, Nigeria. Disponível em: https://kwasuspace.kwasu.edu.ng/handle/123456789/2196.

Adhikari, K., Bhandari, S., Dhakal, L., Shrestha, J. (2020). Fall armyworm (*Spodoptera frugiperda*): A threat in crop production in Africa and Asia. **Europe,** *44*, 4.

Ahmed, K. S.; Idrees, A.; Majeed, M. Z.; Majeed, M. I.; Shehzad, M. Z.; Ullah, M. I.; Afzal, A.; Li, J. (2022). Synergized toxicity of promising plant extracts and synthetic chemicals against fall armyworm *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) in Pakistan. **Agronomy**, 12, 1289. https://doi.org/10.3390/agronomy12061289

Ahmed, K. S.; Majeed, M. Z.; Sayed, S.; Albogami, B. Z.; Al-Shuraym, L. A.; Safdar, H.; Ul Haq, I.; Raza, A. B. M. (2023). Synergized toxicity exhibited by indigenous entomopathogenic fungal strains, plant extracts and synthetic insecticides against fall armyworm *Spodoptera frugiperda* (J. E. Smith) under laboratory and semi-field conditions. **Journal of Plant Diseases and Protection**, 130, 1217–1228. https://doi.org/10.1007/s41348-023-00795-9

Albuquerque, F. H. C.; Soares, K. S.; Oliveira, M. A. S. (2017). Atividade antimicrobiana in vitro dos extratos aquosos, hidroalcoólicos e alcoólicos das folhas de espécies da família Myrtaceae frente à cepas de bactérias de interesse. **CBio**, 16. http://dx.doi.org/10.9771/cmbio.v16i2.17989

Ashamo, M. O.; Ileke, K. D.; Onasile, A. I. (2022). Phytochemical compositions and insecticidal efficacy of four agro-waste used as biological control of cowpea beetle, *Callosobruchus maculatus* (Fab.) [Coleoptera: Bruchidae]. **Bulletin of the National Research Centre**, 46, 108. https://doi.org/10.1186/s42269-022-00795-z

Azad, A.; Khorrami, M. K.; Mohammadi, M. (2025). Determining organophosphorus pesticides in agriculture: A combined approach of ion-mobility spectrometry with robust principal component analysis and multivariate adaptive regression splines. **International Journal of Mass Spectrometry**, 509, 117407.

Cardoso, J. E.; Viana, F. M. P. (2011). Impacto potencial das mudanças climáticas sobre as doenças do cajueiro no Brasil. In R. Ghini, E. Hamada & W. Bettiol (Eds.), **Impactos das Mudanças Climáticas Sobre Doenças de Importantes Culturas No Brasil** (pp. 161–176).

Carvalho, M. d., and Halecki, W. (2021). Modeling of cowpea (Vigna unguiculata) yield and control insecticide exposure in a semi-arid region. **Plants**, 10, 1074.https://doi.org/10.3390/plants10061074.

Chowdhury, S. K.; Banerjee, M.; Basnett, D.; Mazumdar, T. (2024). Natural pesticides for pest control in agricultural crops: an alternative and eco-friendly method. **Plant Science Today**, 11, 433–450.

Corrêa, J. C. R.; Salgado, H. R. N. (2011). Atividade inseticida das plantas e aplicações: revisão. **Revista Brasileira de Plantas Medicinais**, 13, 500–506. https://doi.org/10.1590/S1516-05722011000400016

Costa, R. G.; Da Silva, D. A.; Alves, S. F. (2019). Obtenção e caracterização do extrato fluido de *Genipa americana* Linnaeus. **Revista Eletrônica de Farmácia**, 16, 7. https://doi.org/10.5216/ref.v16.47461

Day, R.; Abrahams, P.; Bateman, M.; Beale, T.; Clottey, V.; Cock, M.; Colmenarez, Y.; Corniani, N.; Early, R.; Godwin, J. (2017). Fall armyworm: impacts and implications for Africa. **Outlooks on Pest Management**, 28, 196–201.

Duveiller, E.; Singh, R. P.; Nicol, J. M. (2007). The challenges of maintaining wheat productivity: pests, diseases, and potential epidemics. **Euphytica**, 157, 417–430. https://doi.org/10.1007/s10681-007-9380-z

EFSA Panel on Plant Health (PLH), Jeger, M.; Bragard, C.; Caffier, D.; Candresse, T.; Chatzivassiliou, E.; MacLeod, A. (2017). Pest categorisation of *Spodoptera frugiperda*. **Efsa Journal**, *15*(7), e04927.

El-Saghier, A. M.; Enaili, S. S.; Kadry, A. M.; Abdou, A.; Gad, M. A. (2023). Green synthesis, biological and molecular docking of some novel sulfonamide thiadiazole derivatives as potential insecticidal against *Spodoptera littoralis*. **Scientific Reports**, 13, 19142. https://doi.org/10.1038/s41598-023-46602-1

Fan, M.; Shen, J.; Yuan, L.; Jiang, R.; Chen, X.; Davies, W. J.; Zhang, F. (2012). Improving crop productivity and resource use efficiency to ensure food security and environmental quality in China. **Journal of Experimental Botany**, 63, 13–24.

Farias, P. R. S.; Barbosa, J. C.; Busoli, A. C. (2001). Amostragem seqüencial (presença-ausência) para *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae) na cultura do milho. **Neotropical Entomology**, 30, 691–695. https://doi.org/10.1590/S1519-566X2001000400026

Goergen, G.; Kumar, P. L.; Sankung, S. B.; Togola, A.; Tamò, M. (2016). First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), a new alien invasive pest in West and Central Africa. **PLOS ONE**, 11, e0165632.

Henagamage, A. P.; Ranaweera, M. N.; Peries, C. M.; Premetilake, M. M. S. N. (2023). Repellent, antifeedant and toxic effects of plants-extracts against *Spodoptera frugiperda* larvae (fall armyworm). **Biocatalysis and agricultural biotechnology**, *48*, 102636.

Hruska, A. J. (2019). Fall armyworm (*Spodoptera frugiperda*) management by smallholders. **CABI Reviews**, 1–11. https://doi.org/10.1079/PAVSNNR201914043

Isman MB. (2016). Botanical insecticides: for richer, for poorer. Pest Manag Sci. 2008 Jan;64(1):8-11. doi: 10.1002/ps.1470. PMID: 18022796.

Pavela, R.; Benelli, G. (2016). Essential oils as ecofriendly biopesticides? Challenges and constraints. **Trends in Plant Science***, 21*(12), 1000–1007. https://doi.org/10.1016/j.tplants.

Instituto Nacional de Meteorologia e Geofísica (INAMET). (2025). *Dados meteorológicos de Angola*. Disponível em INAMET. http://inamet.gov.ao/ao/

Jing, W. A. N.; Huang, C.; Zhang, B.; Xi, Q. I. A. O.; Bo, L. I. U.; Yu, X. I.; Mckirdy, S. (2021). Biology, invasion and management of the agricultural invader: Fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). **Journal of Integrative Agriculture**, *20*(3), 646-663.

Jolliffe, I. T.; Cadima, J. (2016). Principal component analysis: a review and recent developments. *Philosophical transactions.* **Series A, Mathematical, physical, and engineering sciences**, *374*(2065), 20150202.

Jolliffe, I. T.; Cadima, J. (2016). Principal component analysis: a review and recent developments. **Philosophical Transactions of the Royal Society A**, 374, 20150202. https://doi.org/10.1098/rsta.2015.0202

Kenis, M.; Benelli, G.; Biondi, A.; Calatayud, P. A.; Day, R.; Desneux, N.; Wu, K. (2023). Invasiveness, biology, ecology, and management of the fall armyworm, *Spodoptera frugiperda*. **Entomologia Generalis,** *43*(2).

Kinyanjui, G.; Mawcha, K. T.; Malinga, L. N.; Soobramoney, K.; Ṋethononda, P.; Assefa, Y.; Okonkwo, C. O.; Ndolo, D. (2025). Managing African Armyworm outbreaks in Sub-Saharan Africa: current strategies and future directions. **Insects**, 16, 645. https://doi.org/10.3390/insects16060645

Kiobia, D. O.; Mwitta, C. J.; Fue, K. G.; Schmidt, J. M.; Riley, D. G.; Rains, G. C. (2023). A review of successes and impeding challenges of IoT-based insect pest detection systems for estimating agroecosystem health and productivity of cotton. **Sensors**, 23, 4127.

Langa, J. L. (2025). *Avaliação da eficácia de pesticidas orgânicos no controlo de pragas do algodão (Gossypium hirsutum L.)* (TFC). Universidade Eduardo Mondlane, Maputo.

Lautenschläger, T.; Neinhuis, C.; Clausnitzer, V., et al. (2014). Riquezas naturais de Uíge – uma breve introdução sobre o estado atual, a utilização, a ameaça e a preservação da biodiversidade.

Lapornik, B.; Prošek, M.; Wondra, A. G. (2005). Comparison of extracts prepared from plant by-products using different solvents and extraction time. **Journal of Food Engineering**, 71, 214–222.

Lengai, G. M.; Fulano, A. M.; Muthomi, J. W. (2022). Improving access to export market for fresh vegetables through reduction of phytosanitary and pesticide residue constraints. **Sustainability**, 14, 8183.

Li, X.; Hash, J. M.; Hartop, E.; Yang, D.; Smith, P. T.; Brown, B. V. (2025). A molecular phylogeny of scuttle flies (Diptera: Phoridae) unveils extensive concordance but intriguing divergences from morphological results. **Systematic Entomology**, 50, 68–81. https://doi.org/10.1111/syen.12644

Lima, J. A. (2020). *Estabilidade e adaptabilidade de híbridos de milho (Zea mays L.) em diferentes ambientes no Norte de Mato Grosso e Sudeste de Rondônia* (Dissertação). Universidade do Estado de Mato Grosso, Mato Grosso, Brazil.

Mampasi, N.; Munanga, B. (2025). Identification and characterization of the main invasive insects of corn, beans and peanut crops in Dimuca commune, municipality of Negage, Uíge-Angola. **World Journal of Advanced Research and Reviews**, 26, 675–686. https://doi.org/10.30574/wjarr.2025.26.3.2156

Martínez, L. C.; Plata-Rueda, A.; Serrão, J. E. (2021). Effects of insect growth regulators on mortality, survival, and feeding of *Euprosterna elaeasa* (Lepidoptera: Limacodidae) larvae. **Agronomy**, 11, 2002.

Massimbe, I. A.; Nanelo, R. F.; Mapsanganhe, E. J. G. (2023). *Avaliação da eficiência de diferentes biopesticidas no controlo da lagarta do funil do milho (Spodoptera frugiperda) na cultura do milho (Zea mays) no campo experimental do ISPG, distrito de Chókwè* (PhD Thesis). ISPG.

Mendes, S. M.; Boregas, K. G. B.; Lopes, M. E.; Waquil, M. S.; Waquil, J. M. (2011). Respostas da lagarta-do-cartucho a milho geneticamente modificado expressando a toxina Cry1A(b). **Pesquisa Agropecuária Brasileira**, 46, 239–244. https://doi.org/10.1590/S0100-204X2011000300003

Mendesil, E.; Tefera, T.; Blanco, C. A.; Paula-Moraes, S. V.; Huang, F.; Viteri, D. M.; Hutchison, W. D. (2023). The invasive fall armyworm, Spodoptera frugiperda, in Africa and Asia: responding to the food security challenge, with priorities for integrated pest management research. **Journal of Plant Diseases and Protection**, *130*(6), 1175-1206.

Mengesha, G. G.; Salo, S. K.; Fantaye, F. Y.; Mohammed, K. B. (2023). Geographic distribution, relative importance, and association of factors influencing fall armyworm [Spodoptera frugiperda (Smith)

(*Lepidoptera: Noctuidae*)] on maize (Zea mays L.) in Southern Ethiopia. **International Journal of Pest Management**, *69*(3), 255-269.

Miresmailli S, Isman MB. (2013). Botanical insecticides inspired by plant-herbivore chemical interactions. **Trends Plant Sci**. 2014 Jan;19(1):29-35. doi: 10.1016/j.tplants.10.002. Epub 2013 Nov 8. PMID: 24216132.

Miresmailli, S.; Isman, M. B. (2014). Botanical insecticides inspired by plant–herbivore chemical interactions. **Trends in Plant Science**, 19, 29–35. https://doi.org/10.1016/j.tplants.2013.10.002

Mkindi, A. G. (2020). Enhancement of plant extracts use for pest control and growth promotion of common bean (Dissertação). Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania.

Montgomery, D. C. (2017). *Design and analysis of experiments*. John Wiley & Sons, New York.

Montgomery, D.C. (2017) Design and Analysis of Experiments Arisona, State University. Ninth Edition, John Wiley & Sons, New York, 640 p.

Mukanga, M.; Machuku, O.; Chipabika, G.; Matimelo, M.; Mumba, K.; Mabote, N. D.; Simwinga, V.; Nthenga, I.; Lupulula, M.; Misengo Tembo, S.; Lwinya, K. (2022). Bio-efficacy of crude aqueous leaf extracts against the fall armyworm (*Spodoptera frugiperda*) and maize ear rots in Zambia. **ABR**, 3, 38–49. https://doi.org/10.26855/abr.2022.11.001

Nemeyimana, J.; Muhooozi, R.; Nuwagira, U.; Ssenkuba, F. (2023). The efficacy of *Tephrosia vogelii* and *Azadirachta indica* leaf extract combinations against fall armyworm, *Spodoptera frugiperda*, in maize. **Preprint**, 19. `https://doi.org/10.21203/rs.3.rs-3237815/v1` (doi.org in Bing)

Ngegba, P. M.; Cui, G.; Khalid, M. Z.; Li, Y.; Zhong, G. (2022). Prospects of botanical compounds and pesticides as sustainable management strategies against *Spodoptera frugiperda*. **Journal of Economic Entomology**, 115, 1834–1845.

Njuguna, E.; Nethononda, P.; Maredia, K.; Mbabazi, R.; Kachapulula, P.; Rowe, A.; Ndolo, D. (2021). Experiences and perspectives on *spodoptera frugiperda* (Lepidoptera: Noctuidae) management in Sub-Saharan Africa. **Journal of Integrated Pest Management**, *12*(1), 7.

Nwozo, O. S.; Effiong, E. M.; Aja, P. M.; Awuchi, C. G. (2023). Antioxidant, phytochemical, and therapeutic properties of medicinal plants: a review. **International Journal of Food Properties**, 26, 359–388. https://doi.org/10.1080/10942912.2022.2157425

Okwute, S. K. (2012). Plants as potential sources of pesticidal agents. In *Pesticides:* **advances in chemical and botanical pesticides** (pp. 207–320).

Oliveira, G. A. R. (2014). Otimização de processos de extração de princípios ativos de plantas. **Revista Proc. Q.**, 8, 33–41. https://doi.org/10.19142/rpq.v8i16.219

Padial, I. M. P. M. (2025). Impacto de extratos botânicos aquosos em *Plutella xylostella* L. (1758): estudos de antibiose e antixenose.

Parajuli, S.; Shrestha, J.; Subedi, S.; Pandey, M. (2022). Biopesticides: a sustainable approach for pest management. **SAARC Journal of Agriculture**, 20, 1–13.

Peron, F.; Ferreira, G. C. A. (2012). Potencial inseticida de extrato de sementes de mamona (*Ricinus communis* L.) no controle da lagarta-do-cartucho (*Spodoptera frugiperda*). VI Mostra Interna de Trabalhos de Iniciação Científica, 97–105.

Phambala, K.; Tembo, Y.; Kasambala, T.; Kabambe, V. H.; Stevenson, P. C.; Belmain, S. R. (2020). Bioactivity of common pesticidal plants on fall armyworm larvae (*Spodoptera frugiperda*). **Plants**, *9*(1), 112.

Ponte, A. A.; Dias, V.; Maria, E.; de Mendonça, C. E. A. (2022). Métodos industriais para mensuração do teor de etanol em kombuchas. **Revista Eletrônica da Estácio Recife**, 8.

Prasoona, U. S. (2020). *Master of Science in Agriculture (Agricultural Entomology)*. Department of Agricultural Entomology Post Graduate Institute, Akola.

Qie, X.; Sun, A.; Hao, H.; Lv, B.; Wu, W.; Hu, Z. (2022). A potential lignan botanical insecticide from *Phryma leptostachya* against *Aedes aegypti*: laboratory selection, metabolic mechanism, and resistance risk assessment. **Journal of Pest Science**, 95, 397–408. https://doi.org/10.1007/s10340-021-01389-w

Rioba, N. B.; Stevenson, P. C. (2020). Opportunities and scope for botanical extracts and products for the management of fall armyworm (*Spodoptera frugiperda*) for smallholders in Africa. **Plants**, 9, 207. https://doi.org/10.3390/plants9020207

Rodrigues de Lima, R., & da Silva, F. P. (2022). NIM (*Azadirachta indica*): UMA ABORDAGEM SOBRE USO COMO INSETICIDA NATURAL. **REVISTA CIENTÍFICA ACERTTE** - *ISSN 2763-8928*, *2*(10), e21099. https://doi.org/10.47820/acertte.v2i10.99

Rosa, M. J. Z.; Faccin, F. F.; de Oliveira, D. L. (2019). Análise de desempenho e padronização de atividades de uma coluna de destilação com recheio. **Revista**, 10, 7–14.

Rwomushana, I. (2019). Spodoptera frugiperda (fall armyworm). *Invasive Species Compendium*, *29810*(10.1079).

Saeidi, S.; Forgani, F.; Javadian, F.; Javadian, E. (2019). Effects of *Rosmarinus officinalis* plant extract on *Trichomonas vaginalis* parasites and *Candida albicans* under laboratory conditions: an experimental study. **Gene, Cell and Tissue**, 6, 1–6.

Santos Junior, J. J. P.; Pereira, R. G.; Rosendahl, M.; Santo Filho, D. M. E.; Gouveia, J. M. G. (2020). The use of ethanol to determine the volume of a pycnometer used to measure the density of liquids at different temperatures and pressures. **Journal of the Brazilian Society of Mechanical Sciences and Engineering**, 42, 50. https://doi.org/10.1007/s40430-019-2107-y

Sisay, B.; Tefera, T.; Wakgari, M.; Ayalew, G.; Mendesil, E. (2019). The efficacy of selected synthetic insecticides and botanicals against fall armyworm, *Spodoptera frugiperda*, in maize. **Insects**, *10*(2), 45.

Soyel, S. A.; Ruidas, S.; Roy, P.; Mondal, S.; Bhattacharyya, S.; Hazra, D. K. (2023). Biopesticides as eco-friendly substitutes to synthetic pesticides: an insight of present status and future prospects with improved bio-effectiveness, shelf-lives, and climate resilience. **International Journal**, 2, 1–12.

Tanyi, C. B.; Nkongho, R. N.; Okolle, J. N.; Tening, A. S.; Ngosong, C. (2020). Effect of intercropping beans with maize and botanical extract on fall armyworm (*Spodoptera frugiperda*) infestation. **International Journal of Agronomy**, *2020* (1), 4618190.

Togola, A.; Beyene, Y.; Bocco, R.; Tepa-Yotto, G.; Gowda, M.; Too, A.; Boddupalli, P. (2025). Fall armyworm (*Spodoptera frugiperda*) in Africa: insights into biology, ecology and impact on staple crops, food systems and management approaches. **Frontiers in Agronomy**, 7, 1538198.

Tulashie, S. K.; Adjei, F.; Abraham, J.; Addo, E. (2021). Potential of neem extracts as natural insecticide against fall armyworm (*Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae). **Case Studies in Chemical and Environmental Engineering**, *4*, 100130.

Valicente, F. H. (2020). Controle biológico da lagarta do cartucho, *Spodoptera frugiperda*, com *Bacillus thuringiensis*. No. 105, Sete Lagoas, MG, 9 p. ISSN 1518-4269. Disponível em: https://www.embrapa.br/busca-de-publicacoes/-/publicacao/105 (embrapa.br in Bing).