



Effectiveness of Natural Insecticides in the Sustainable Management of the Maize Weevil (*Sitophilus zeamais*) in Stored Grains in the Angolan Context

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ABSTRACT

The maize weevil (*Sitophilus zeamais*) is a major pest of stored maize, causing substantial losses in grain quantity and quality. While chemical insecticides are commonly used for control, they pose environmental and human health risks. Botanical and biological insecticides offer sustainable and safe alternatives, effectively managing pests without the adverse effects associated with synthetic products. This study evaluated the efficacy of three botanical insecticides, neem leaf powder (*Azadirachta indica*), calembé leaf powder (*Tephrosia vogelii*), and wood ash, and two biological agents, *Beauveria bassiana* and Di Grow Bio 8, against *S. zeamais* under laboratory conditions. Each treatment was applied to 100 g of maize grains, which were then infested with 20 unsexed adult weevils. The experiment followed a completely randomised design with five replicates and a control, and data were analysed using SPSS 15.0 with means compared by Tukey's test at 5% probability. Wood ash achieved the highest mortality (77%), followed by *B. bassiana* (65%) and Di Grow Bio 8 (56%), while neem (*A. indica*) and calembé (*T. vogelii*) reached 40% mortality. All treatments differed significantly from the control. These results indicate that wood ash is an effective, low-cost, and sustainable alternative for managing maize weevils in stored maize.

Keywords: *Sitophilus zeamais*; botanical insecticides; biological insecticides; stored maize.

Eficiência de Inseticidas Naturais no Maneio Sustentável do Gorgulho-do-Milho (*Sitophilus zeamais*) em Grãos Armazenados em Contexto Angolano

RESUMO

O gorgulho (*Sitophilus zeamais*) é uma das principais pragas do milho armazenado, causando perdas significativas na produção e qualidade dos grãos. Embora o uso de inseticidas químicos seja comum, ele apresenta riscos ambientais e à saúde humana. Inseticidas botânicos e biológicos surgem como alternativas sustentáveis e seguras, capazes de controlar pragas sem efeitos adversos associados a produtos sintéticos. Este estudo avaliou o efeito de três inseticidas botânicos, pó de folhas de neem (*Azadirachta indica*), pó de folhas de calembé (*Tephrosia vogelii*) e cinza de madeira, e dois biológicos, *Beauveria bassiana* e Di Grow Bio 8, sobre o controle do gorgulho em condições de laboratório. Cada tratamento foi aplicado em 100 g de grãos de milho e infestados com 20 adultos de *S. zeamais*, seguindo delineamento inteiramente casualizado com cinco repetições e uma testemunha. Os dados foram analisados pelo SPSS 15.0 e comparados pelo teste de Tukey a 5% de probabilidade. O tratamento com cinza de madeira obteve a maior mortalidade (77%), seguido por *Beauveria bassiana* (65%) e Di Grow Bio 8 (56%), enquanto neem (*A. indica*) e calembé (*T. vogelii*) apresentaram 40%. Todos os tratamentos diferiram significativamente da testemunha. Os resultados indicam que a cinza de madeira representa uma alternativa eficaz, acessível e sustentável para o manejo do gorgulho em milho armazenado.

Palavras-chave: *Sitophilus zeamais*; inseticidas botânicos; inseticidas biológicos; milho armazenado.

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1. Introduction

Maize (*Zea mays* L.) plays a critical role in global food security and, particularly, in Africa and Angola, where it constitutes a staple food for millions of people, especially in rural areas (Saeed & Laing, 2023; Asibe et al., 2023). Beyond its nutritional importance, maize is also a key component of household economies. However, its sustainability is severely threatened by the maize weevil, *Sitophilus zeamais* (Motschulsky), a primary pest that attacks grains both in the field and during storage. Infestations by *S. zeamais* lead to substantial losses in grain weight and nutritional quality, often reaching critical levels, particularly in traditional storage systems where conditions are generally inadequate (Saeed & Laing, 2023). This poses a direct threat to household food security in Angola (Asibe et al., 2023).

Historically, the protection of stored grains against *S. zeamais* has relied predominantly on synthetic chemical insecticides (Amaro & Gouveia, 1957). In the Angolan context, however, the continuous use of these commercial products faces severe practical constraints, particularly for smallholder farmers who deal with high acquisition costs and irregular supply chains in rural markets (De Matos, 2011; Pacavira, 2004). Furthermore, the application of synthetics without adequate training or personal protective equipment, combined with the emergence of pest resistance, has amplified both environmental contamination and public health risks in Sub-Saharan Africa (Asibe et al., 2023; Phokwe & Manganyi, 2023). Consequently, validating low-cost, locally available alternatives has become an essential step toward establishing sustainable post-harvest management strategies.

In this context, natural insecticides emerge as a promising strategy within integrated pest management systems. Botanical insecticides such as neem (*Azadirachta indica*) and calembé (*Tephrosia vogelii*), both widely available in Angola, as well as traditional methods like wood ash application, have demonstrated insecticidal and repellent properties (De Matos, 2011; Borsonaro et al., 2013). In parallel, biological agents such as the entomopathogenic fungus *Beauveria bassiana* represent an innovative approach, targeting pests without leaving toxic residues in food products (Liu et al., 2022).

Despite the well-known bioactivity of these natural resources, their transition from traditional practices to broad agronomic adoption remains limited. A primary constraint is the high variability in the efficacy of botanical extracts, which depends on plant phenology, extraction methods, and the stability of active compounds over time (Gottardi, 2014). Without standardised application protocols and locally validated dosages, smallholders often face inconsistent control results under storage conditions (Pimentel et al., 2019). Therefore, testing these regional solutions under controlled laboratory parameters is a critical step to establish reliable, reproducible, and safe guidelines that can effectively support small- and medium-scale farmers (Garcia, 2014).

In Angola, the management of stored grain pests is closely tied to high post-harvest vulnerability, as traditional storage structures often fail to prevent insect proliferation (Pacavira, 2004). While synthetic insecticides remain a common response, their continuous use by smallholders is frequently limited by economic barriers, such as high acquisition costs, alongside severe health risks arising from a lack of appropriate safety equipment and formal application training (De Matos, 2011; Phokwe & Manganyi, 2023). Furthermore, improper chemical applications under these constraints can accelerate pest resistance without delivering effective control (Asibe et al., 2023). Within the framework of integrated pest management, this scenario underscores the urgency of validating safer, decentralized alternatives rooted in locally available resources. Consequently, this study aims to evaluate and compare the insecticidal efficacy of select botanical powders, wood ash, and biological agents against the maize weevil (*Sitophilus zeamais*) under controlled laboratory conditions.

The proposed research question is: what is the comparative efficacy of botanical insecticides (neem, calembé, and wood ash) and biological agents (*Beauveria bassiana* and Di Grow Bio 8) in terms of mortality and control of *S. zeamais* under laboratory conditions? Based on this question, the following hypotheses were formulated: (i) Botanical and biological insecticides result in significantly higher mortality rates compared to the untreated control; (ii) Wood ash and neem leaf powder exhibit the highest immediate effectiveness due to

their abrasive and repellent properties; (iii) Natural treatments produce sublethal effects, reducing reproduction and the emergence of new individuals in the F₁ generation.

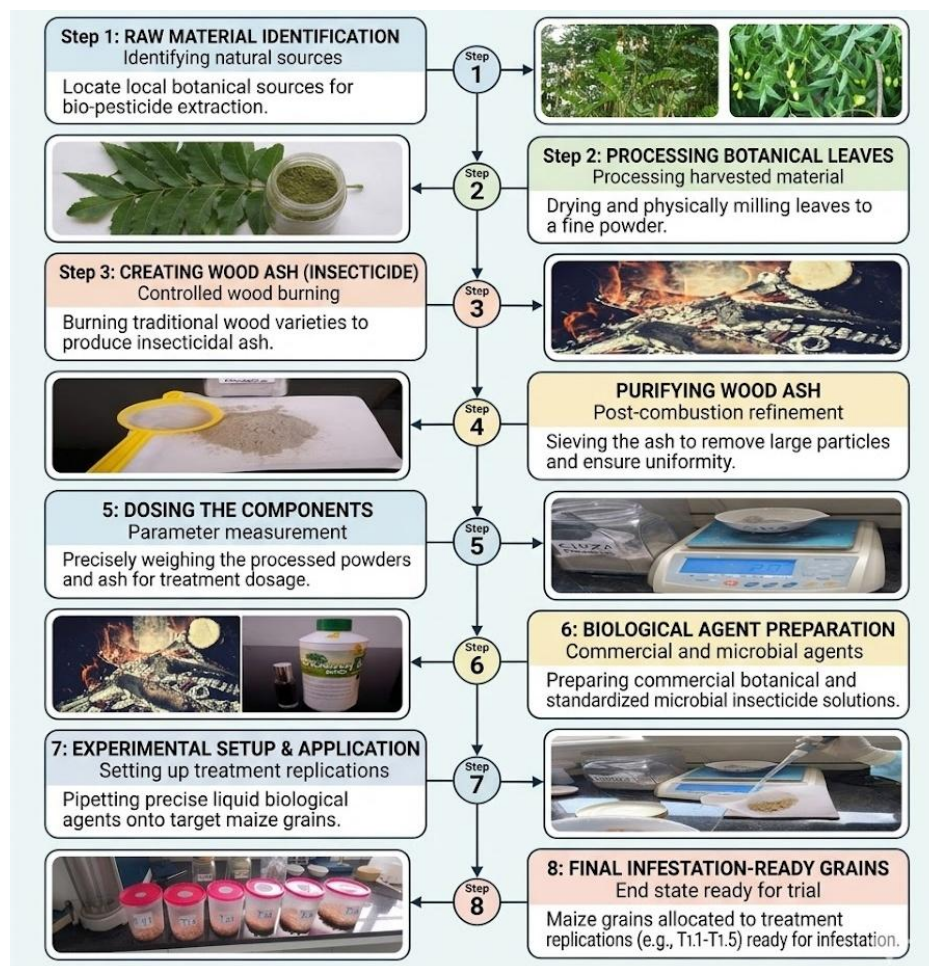
To address the hypothesis, we define these specific objectives of the study are: (i) To determine the mortality rate of adult *S. zeamays* exposed to different treatments over time; (ii) To assess the effect of treatments on infestation levels and grain weight loss; (iii) To identify the most cost-effective treatment for small-scale application in the Angolan context.

2. Methodology

2.1 Study site and experimental procedures

The study was conducted at the Food Technology Teaching and Research Laboratory, Faculty of Veterinary Medicine, José Eduardo dos Santos University, Huambo, Angola, from December 2023 to March 2024. Based in Saeed & Laing (2023), the experimental substrate consisted of yellow maize (*Zea mays* L.), cultivar Pan 12, purchased from a local market. Prior to the experiment, the grains were manually inspected and cleaned to remove impurities, broken grains, and any pre-existing infestations, ensuring uniformity for the bioassays. Figure 1 illustrate the methodological workflow of the study.

Figure 1. Methodological workflow for stored grain bio-pesticide efficiency analysis



Source: Authors (2026)

Botanical insecticides were prepared from leaves of *A. indica* (neem) and *T. vogelii* (calembe), collected from naturally growing trees in the municipalities of Sumbe and Cassongue, Cuanza Sul Province. The leaves were air-dried in the shade for approximately ten days until they reached constant weight. Once dry, the leaves were ground and sieved through a 1.5 mm mesh to produce a fine, homogeneous powder, which was stored in sterilised glass containers at approximately 20 °C until use.

Wood ash was obtained from the controlled burning of *Julbernardia paniculata* (Olumue) and *Brachystegia spiciformis* (Anduko), trees commonly used for charcoal production in Huambo Province (Miapia et al., 2021). The ash was sieved to remove impurities and stored in a dry place until application.

Biological control agents included the entomopathogenic fungus *B. Bassiana* (Liu et al., 2022), supplied by the Polytechnic Institute of Bragança, Portugal, and the commercial biofertiliser Di Grow Bio 8, manufactured in Malaysia, containing *B. bassiana*, *Metarhizium anisopliae*, and other components that support plant defence mechanisms. Maize weevils (*S. zeamais*) were maintained in 4 L plastic containers with ventilated mesh lids to allow oxygen circulation while preventing escape. The insects were reared on untreated maize grains and used for infestation in the bioassays.

2.2 Measured parameters and statistical analysis

The experiment followed a completely randomised design (CRD) with six treatments and five replicates each, totalling thirty experimental units. Treatments included: neem leaf powder, calembe leaf powder, wood ash, *B. bassiana*, Di Grow Bio 8, and an untreated control.

Each experimental unit consisted of a 500 mL plastic container containing 100 g of maize grains. Botanical powders were applied at a rate of 2 g per 100 g of grain, and biological treatments were diluted to 1 mL per 100 mL of water and applied evenly to the grains. The containers were manually shaken for one minute to ensure uniform adhesion of the treatments.

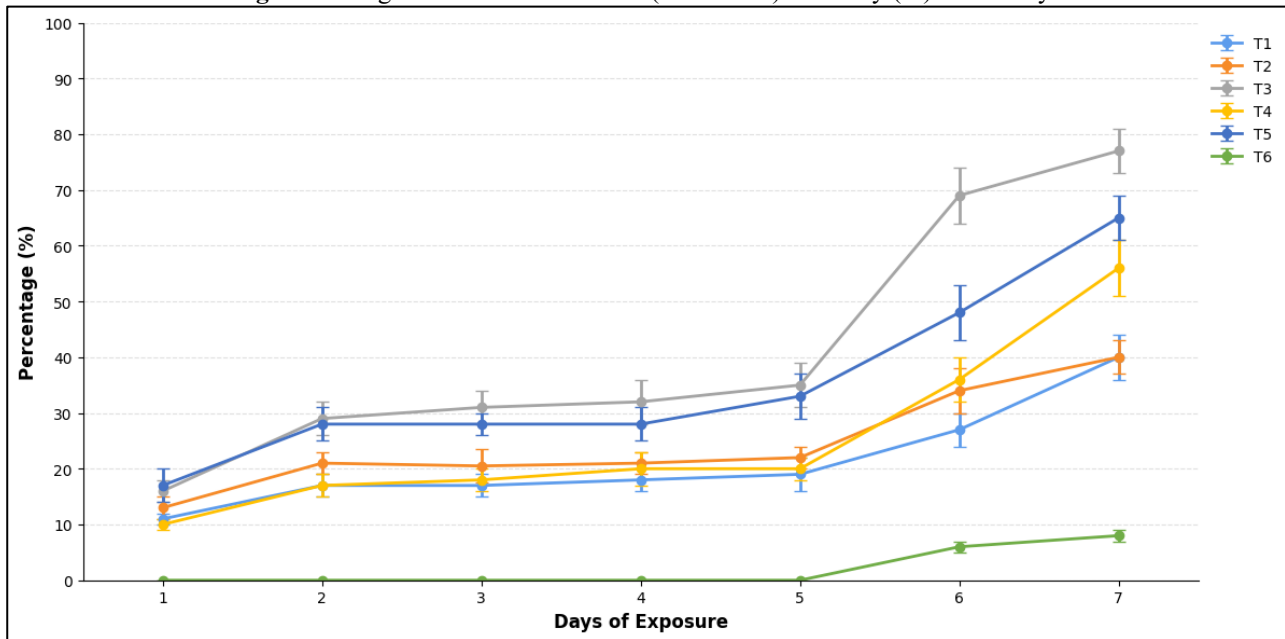
Each container was infested with twenty unsexed adult *S. zeamais* insects, following established bioassay procedures. Insect mortality was observed daily over seven days. An insect was considered dead if it remained immobile for two to five minutes after gentle physical stimulation. The data were analysed using SPSS version 15.0 and Colab Pro. Differences among treatment means were determined using Tukey's test at a 5% probability level ($p \leq 0.05$).

3. Results and Discussion

Evaluations were conducted over a seven-day period following the setup of the experiment in the laboratory. Insect mortality was recorded, with individuals considered dead if they failed to respond to stimulation with a brush. The results demonstrated significant effects of the different treatments and their interaction with the doses applied on weevil mortality.

3.1. Progression of mortality of the maize weevil (*S. zeamais*) over seven days

The daily monitoring of *S. zeamais* revealed distinct patterns in the speed of action and insecticidal efficacy among the evaluated treatments (Figure 2). During the initial 24 hours post-exposure, all alternative treatments induced significantly higher mortality rates than the untreated control ($p < 0.05$), which remained at 0%. At this early stage, the biological agent *B. bassiana* (T5) and the traditional treatment of wood ash (T3) exhibited the fastest initial impact, reaching mortality rates of 17% and 16%, respectively. In contrast, the botanical treatments of neem (T1) and the bio-fertilizer (agent) Di Grow Bio 8 (T4) showed a slower immediate effect, with mortality percentages restricted to 10% and 11%. This initial variation suggests differences in the breakdown and penetration pathways of the active components during acute exposure.

Figure 2. Progression of maize weevil (*S. zeamais*) mortality (%) over 7 days

Source: Authors (2026)

From the second to the fifth day, mortality rates showed minor fluctuations. T1 (Neem), T2 (*Tephrosia*), and T4 (Di Grow Bio 8) exhibited relatively stable mortality, while T3 (Wood Ash) and T5 (*B. bassiana*) showed an accelerated increase compared with the other treatments. According to Schumutterer (1988), insect mortality depends on both the dose and exposure time to the active ingredient, which strongly aligns with the delayed action observed in these bio-insecticides during this study.

By the sixth day, a clearer differentiation between treatments emerged. T1 (Neem) showed the lowest treatment mortality at 27%, while T2 (*Tephrosia*) and T4 (Di Grow Bio 8) ranged between 34–36%. The highest mortality was observed in T3 (Wood Ash) and T5 (*B. bassiana*), reaching 69% and 48%, respectively. Silva (2006) highlights that *B. bassiana* is widely used in Brazil (Pimentel et al., 2012; Parra, 2019) and worldwide (Liu et al., 2022; Saeed e Laing, 2023) due to its low-cost production and its mode of action via direct contact with the host cuticle.

At the end of the evaluation period on the seventh day, T3 (Wood Ash) proved to be the most effective treatment, peaking at 77% mortality. This was followed by T5 (*B. bassiana*) with 65% and T4 (Di Grow Bio 8) with 56%. The botanical powders, T1 (Neem) and T2 (*Tephrosia*), plateaued at 40%. The control group (T6) showed minimal natural mortality (8%) by day 7, confirming the reliability of the bioassay. The superior performance of wood ash highlights a highly accessible and zero-cost alternative for small-scale Angolan farmers facing challenges with synthetic pesticide resistance.

3.2. Statistical analysis of maize weevil mortality

Statistical analysis using ANOVA, with mean comparisons by Tukey's test ($p < 0.05$), revealed the following patterns of *S. zeamais* mortality over the seven-day period. See Table 1.

Table 1. Mean mortality (%) of *S. zeamais* following the application of botanical insecticides (neem leaf powder, *T. vogelii* leaf powder, and wood ash) and biological insecticides (*B. bassiana* and Di Grow Bio 8) under laboratory conditions

Days	Treatments					
	T1 (Neem)	T2 (<i>Tephrosia</i>)	T3 (Wood ash)	T4 (Di Grow Bio 8)	T5 (<i>B. bassiana</i>)	T6 (Control)
1 st day	11a	13b	16c	10a	17c	00e
2 nd day	17a	21b	29c	17a	28c	00e
3 rd day	17a	20,6a	31c	18a	28c	00e
4 th day	18a	21b	32c	19a	28d	00e
5 th day	19a	23b	35c	20a	33c	00e
6 th day	27a	33b	69c	30b	48d	00e
7 th day	40a	40a	77c	56b	65d	8e

Means followed by the same letters in the row do not differ significantly according to Tukey's test at the 5% probability level.

Fonte: Autores (2026)

For day 1, T1 (Neem) and T4 (Di Grow Bio 8) exhibited low mortality rates of 10% and 11%, respectively, and did not differ significantly. T2 (*Tephrosia*) showed slightly higher mortality at 13%, which was significantly different from T1 and T4. T3 (Wood Ash) and T5 (*Beauveria bassiana*) recorded the highest mortalities of 16% and 17%, which were not significantly different from each other. All treatments had mortality rates significantly higher than the control (0%).

In day 2, T1 (Neem) and T4 (Di Grow Bio 8) remained similar, showing no significant difference. T2 (*Tephrosia*) increased to 21% mortality, differing significantly from T1 and T4. T3 (Wood Ash) and T5 (*Beauveria bassiana*) recorded 28% and 29%, respectively, without a significant difference between them.

In the 3rd day 3, T1 (17%), T2 (20.6%), and T4 (18%) maintained similar, relatively low mortalities. T3 (29%) and T5 (28%) exhibited higher mortalities, significantly exceeding those of T1, T2, and T4. All treatments differed significantly from the control.

For day 4, T3 (Wood Ash) had the highest mortality (32%), followed by T5 (*B. bassiana*) with 28%, and these two differed significantly from each other. T2 (*Tephrosia*) had 21% mortality, significantly higher than T1 (18%) and T4 (19%), which did not differ from each other. All treatments showed mortality significantly greater than the control (see Table 1).

The 5th day 5, T3 (35%) and T5 (33%) remained the treatments with the highest mortalities, without a significant difference between them. T1 (19%) and T4 (20%) continued to show lower mortalities, also not differing significantly from each other.

In day 6, T1 (Neem) had the lowest mortality (27%), differing significantly from the other treatments. T3 (Wood Ash) achieved the highest mortality (69%), significantly exceeding all other treatments. T2 (*Tephrosia*) and T4 (Di Grow Bio 8) had intermediate mortalities, while T5 (*B. bassiana*) also showed high mortality. All treatments were significantly higher than the control.

The last day (day 7), maximum mortalities were observed for T3 (77%) and T5 (65%), followed by T4 (56%). T1 (Neem) and T2 (*Tephrosia*) recorded lower mortalities of 40%, and the control had only 8%. These results indicate that T3 (Wood Ash) and T5 (*B. bassiana*) were the most effective treatments. Wood ash, being readily obtainable and reusable, represents a cost-effective option for practical application. The lower mortalities observed in T1 (Neem) and T2 (*Tephrosia*) are likely due to the short exposure time (7 days) and the dusting application method (see Figure 2 and Table 1).

3.3. Discussion on progression of mortality and statistical analysis of the maize weevil

The relatively low efficacy of T1 (Neem) and T2 (*Tephrosia*) on *S. zeamais* mortality observed in this study (Table 1) is likely related to the concentration of the products used, the short exposure time, and the application method (dusting). However, these results differ from those reported by Rosa (2011), who observed high mortality using aqueous extracts of Neem and *Tephrosia* against maize weevils. Delobel and Malonga (1987) reported 98.8% mortality after 13 days when maize seeds were dusted with *Tephrosia* in rural extension programmes in the Republic of Congo. Similarly, Gottardi (2014) found that neem oil at 2 L/t achieved 100% mortality of *S. zeamais* up to 60 days post-application.

The limited effect of Neem in the present study may be attributed to the product's sensitivity to photodegradation. The active compounds in Neem degrade slowly, particularly in formulations containing 99% carrier and only 1% active ingredient, which reduces volatilisation compared with pure oil and prolongs the persistence of activity (Gottardi, 2014).

De Matos (2011) highlights that the high dependence on synthetic insecticides in Angola and sub-Saharan Africa has led to pest resistance, environmental contamination, and human health risks. In this context, the results of the present study demonstrate that botanical and biological insecticides provide a viable and sustainable alternative for controlling *S. zeamais*. Additionally, plants such as Neem and *Tephrosia*, along with wood ash, are widely available natural resources in the region, facilitating adoption by smallholder farmers and cooperatives.

Although the laboratory results are promising, field efficacy may vary due to environmental factors such as humidity, temperature, and post-harvest management. Therefore, further studies under semi-controlled and field conditions are recommended to evaluate the persistence of botanical and biological insecticides over time and their interactions with different grain storage practices.

Other studies have reported different outcomes. Barilli et al. (2014) observed 60% mortality of *S. zeamais* using 5% Neem combined with wood ash over ten days. Borsonaro et al. (2013) tested neem powder at various aqueous extract concentrations (10%, 20%, and 30.3%) and found a maximum mortality of 44% at 30.3%. The Meliaceae family stands out among botanical families for the number of insecticidal species and the efficiency of their extracts. Their bioinsecticidal properties include inhibition of feeding and disruption of exoskeleton development during moulting. Azadirachtin, the active compound in Neem, also exerts an antifeedant effect via oral ingestion, disrupting gustatory receptor activity and impairing food intake, ultimately causing starvation and death.

The low mortality observed for T2 (*Tephrosia vogelii*) during the seven-day trial (Table 1) may similarly be due to product concentration, exposure time, and dusting application. These results contrast with Lina (2013), who demonstrated high insecticidal activity of *T. vogelii* seed, fruit, and leaf extracts against *Crocidolomia pavonana*, with LC50 = 0.06% and LC95 = 0.12% under laboratory conditions.

The *B. bassiana* treatment (T5) exhibited 65% mortality by Day 7 (Table 1). This aligns with findings by Pimentel and Ferreira (2012), who reported that mortality of *S. zeamais* increased with exposure time to formulations of *B. bassiana* and *M. anisopliae*, with the highest effects observed after five days, regardless of concentration. In contrast, Pimentel et al. (2019) reported only 13.8% efficacy at 10 and 20 g/L doses. Similarly, Agostini et al. (2015) observed low mortality (10%) of *Sitophilus oryzae* within 12 days at 10 g doses. The entomopathogenic fungus *B. bassiana* acts by direct contact, penetrating the host cuticle via spore adhesion, enzymatic degradation, and subsequent fungal colonisation. However, conidial viability is influenced by humidity, temperature, and light, factors which may have affected the outcomes in the present study (Oliveira, 2017).

Wood ash treatment (T3) produced the highest mortality, reaching 77% on Day 7. These results are consistent with Amaro and Gouveia (1957) and Pacavira (2004), who reported 79% mortality of *S. zeamais* using ash from charcoal-producing trees in Malange and Huambo provinces. Garcia (2014) noted that insecticides should achieve at least 80% efficacy to be considered suitable for practical use. Barros et al. (2007) also found that wood ash was the most effective alternative treatment for maize seeds (IAPAR 26) in Paraná,

Brazil, surpassed only by the chemical insecticide malathion.

Overall, these findings underscore the potential of botanical and biological insecticides, particularly wood ash and *Beauveria bassiana*, as sustainable and cost-effective strategies for controlling *Sitophilus zeamais* in stored maize. However, the present study has several limitations that should be considered when interpreting the results. The experiment was conducted under controlled laboratory conditions, which do not fully replicate the variability of on-farm storage environments, where factors such as temperature, relative humidity, grain moisture content, and storage structure can significantly influence insect dynamics and treatment efficacy. In addition, the relatively short evaluation period (seven days) may not have captured the full residual or delayed effects of certain treatments, particularly botanical insecticides, whose activity can depend on prolonged exposure. The use of a single application method (dusting) and fixed concentrations also limits the generalisation of the findings across different practical scenarios.

Given these constraints, further research is recommended under semi-controlled and field conditions to validate the effectiveness and persistence of these treatments over longer storage periods. Future studies should explore different formulations, concentrations, and application techniques, as well as the potential synergistic effects of combining botanical and biological control agents. Moreover, evaluating the impact of these treatments on grain quality, seed viability, and economic feasibility will be essential to support their adoption. Such efforts will contribute to developing integrated, locally adapted pest management strategies for smallholder farmers in Angola and similar agro-ecological contexts.

4. Conclusion

This study demonstrates that both botanical treatments and biological agents possess significant insecticidal activity against *Sitophilus zeamais*, offering viable alternatives to synthetic chemical control. Among the evaluated resources, wood ash emerged as the most effective treatment, achieving the highest cumulative mortality rate (77%) by the seventh day of exposure. This highlights its potential as an immediate, low-cost, and accessible post-harvest protectant for small-scale farming systems.

The biological agents, *Beauveria bassiana* and Di Grow Bio 8, also proved highly capable, though their slightly lower performance (65% and 56% mortality, respectively) suggests that biological control pathways may require longer exposure periods to reach maximum efficacy under storage conditions. In contrast, neem (*A. indica*) and calembé (*T. vogelii*) leaf powders exhibited moderate effectiveness, which underscores the need to optimize application methods and dosages to improve their field potential. These results show that local sustainable resources can reduce pesticide dependency and support food security in Angolan post-harvest management.

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