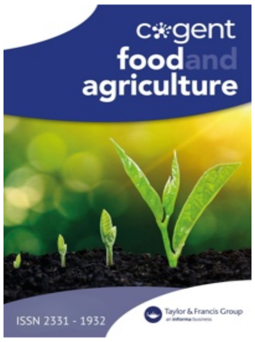

Taylor & Francis
Taylor & Francis Group

Cogent Food & Agriculture

ISSN: 2331-1932 (Online) Journal homepage: www.tandfonline.com/journals/oafa20

Efficacy of *Lippia javanica* leaf powder and *Combretum imberbe* wood ash against the larger grain borer (*Prostephanus truncatus*) in stored maize

Lorraine Yeukai Chihumbiri, Zivanayi Musabayana, Mandhlenkosi Zhou, Ndabanye Mathema, Lenon Tembo & Pesanai Zanamwe

To cite this article: Lorraine Yeukai Chihumbiri, Zivanayi Musabayana, Mandhlenkosi Zhou, Ndabanye Mathema, Lenon Tembo & Pesanai Zanamwe (2026) Efficacy of *Lippia javanica* leaf powder and *Combretum imberbe* wood ash against the larger grain borer (*Prostephanus truncatus*) in stored maize, Cogent Food & Agriculture, 12:1, 2692751, DOI: 10.1080/23311932.2026.2692751

To link to this article: https://doi.org/10.1080/23311932.2026.2692751

© 2026 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group

Published online: 26 Jun 2026.

Submit your article to this journal

Article views: 64

View related articles

View Crossmark data

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=oafa20

COGENT FOOD & AGRICULTURE
2026, VOL. 12, NO. 1, 2692751
https://doi.org/10.1080/23311932.2026.2692751

SOIL & CROP SCIENCES | RESEARCH ARTICLE
OPEN ACCESS Check for updates

Efficacy of *Lippia javanica* leaf powder and *Combretum imberbe* wood ash against the larger grain borer (*Prostephanus truncatus*) in stored maize

Lorraine Yeukai Chihumbiri[a], Zivanayi Musabayana[b], Mandhlenkosi Zhou[b], Ndabanye Mathema[b], Lenon Tembo[b] and Pesanai Zanamwe[b]

[a]Faculty of Agriculture Zimbabwe, Open University, Mt Pleasant, Harare, Zimbabwe; [b]Department of Horticulture and Crop Production, Gwanda State University, Filabusi, Zimbabwe

ABSTRACT
Prostephanus truncatus is a major storage pest responsible for substantial maize grain losses. This study evaluated the efficacy of *Lippia javanica* leaf powder and *Combretum imberbe* wood ash in controlling *P. truncatus* in stored maize. The study consisted of two separate trials, each with six treatments, replicated thrice and arranged in a Completely Randomized Design (CRD). The treatments for the first trial consisted of four dosages of *L. javanica* (2, 4, 6, 8 g) applied to 200 g of maize grain, the untreated control and Actellic Gold Dust. The second trial treatments consisted of four dosages of *C. imberbe* (2, 4, 6, 8 g) applied to 200 g of maize grain, an untreated control and Actellic Gold Dust. Each experimental unit was infested with 10 adult *Prostephanus truncatus*, and assessments were conducted at 7, 14, and 21 days after treatment. The efficacy of *L. javanica* leaf powder and *C. imberbe* in the control of *P. truncatus* was assessed by determining insect mortality, insect reproduction, mean grain weight loss, and mean grain damage. Both biopesticides significantly ($p < 0.05$) increased adult insect mortality and suppressed reproduction compared to the untreated control. The highest mortality (90%) was observed at 8 g for both botanicals and reproduction was reduced by 5–85% relative to the control for *L. javanica* and 10–92% for *C. imberbe,* depending on dosage. The findings demonstrate that *L. javanica* and *C. imberbe* are promising bioinsecticides for maize protection against *P. truncatus*a especially for smallholder farmers.

ARTICLE HISTORY
Received 10 February 2026
Revised 15 June 2026
Accepted 17 June 2026

KEYWORDS
Botanical insecticides; *Combretum imberbe*; grain protection; *Lippia javanica*; maize storage; *Prostephanus truncatus*

SUBJECTS
Plant Ecology; Entomology; Entomology

Introduction

Maize is the main staple food in sub-Saharan Africa, providing a major source of food for millions of people. In Zimbabwe, maize is a vital component of food security, agricultural productivity, and the economy. It is widely consumed in different forms, such as maize meal, alcoholic drinks, breakfast cereals and roasted or popped products (Ekpa et al., 2019). Moreover, maize is a vital component of animal feed. Notwithstanding its importance to the national economy, the production and storage of maize in Zimbabwe, as well as in other tropical countries in Africa, experience significant post-harvest losses as a result of infestation by various insect pests. Storage pests, such as the larger grain borer (*Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae), and the maize weevil (*Sitophilus zeamais*), constitute a major menace to the quality, quantity, and market value of stored grain in tropical Africa (Mutambuki et al., 2019; Ngom et al., 2020). The infestation of these pests in stored grain occurs as soon as the moisture content in the grain falls below 18–20%, thereby creating conducive conditions for their colonisation and population growth (Edoh Ognakossan et al., 2012; Suleiman et al., 2018). Of these two pests, *P. truncatus* is the most destructive particularly because of its ability to bore into and degrade the grain into dust. Again, *P. truncatus* reproduce in stored grain, thereby, accelerating the deterioration of the grain (Anagiotakis et al., 2023; Quellhorst et al., 2021).

CONTACT Lenon Tembo lenontembo@gmail.com Department of Horticulture and Crop Production, Gwanda State University, Epoch Mine Campus, P. O. Box 30 Filabusi, Zimbabwe
© 2026 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group
This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. The terms on which this article has been published allow the posting of the Accepted Manuscript in a repository by the author(s) or with their consent.

This pest causes significant post-harvest losses of stored maize grain. The post-harvest losses in stored grain in tropical Africa have been reported to be as high as 50%, with an average loss of about 20% (Affognon et al., 2015; Arthur et al., 2020). The damage to stored grain by this pest does not only result in losses in grain quantity but also in its nutritional value. Moreover, its damage causes production of allergenic dust that is detrimental not only to the consumer but also to the storage workers themselves (Nowakowska-Świrta et al., 2019). Synthetic pesticides are the most widely used control agents for this pest. While synthetic pesticides are effective and control insect faster, use of synthetic pesticides is also faced with a number of critical limitations. Most synthetic pesticides are unaffordable to small-scale farmers. Moreover, use of synthetic pesticides may expose farmers and grain consumers to potential health hazards (Moreira & Da Silva, 2023). Moreover, use of synthetic pesticides may harm the environment through pollution (retention of toxic residues), and interference with non-target organisms (Arthur et al., 2020). These factors have contributed to the growing concerns regarding the use of synthetic pesticide control agents (Liang et al., 2025; Minozzo et al., 2021). Furthermore, repeated use of synthetic pesticides was reported to be the primary cause of the development of resistance in insect pests (Liang et al., 2025; Pu & Chung, 2024). These factors contributed to the growing global quest for alternative safe, affordable and environmentally friendly control agents (Ileke et al., 2016).

Indigenous knowledge systems and traditional storage mechanisms provides useful insights into the sustainable management of pests. Traditionally, communal farmers in Zimbabwe have used natural materials, including plant products and wood ash, to control storage pests in maize. Studies have shown that botanical extracts and powders (e.g. neem seed, rice husk ash) can significantly reduce *Sitophilus zeamais* populations, lower grain weight loss, and provides a cost-effective, accessible, and environmentally friendly alternative to synthetic pesticides (Akuoli et al., 2024; Ileke et al. 2020; Mapara & Mazuru, 2015; Wini Goudoungou et al. 2018). These developments stimulated interest to validate the traditional approaches using empirical evidence. Many plants species were reported to have pest control attributes, among which are *Eucalyptus* spp., *Tagetes minuta*, *Allium sativum*, *Azadirachta indica*, *Tephrosia vogelii*, *Euphorbia tirucalli*, *Ocimum* spp, *Combretum imberbe* and *Lippia javanica* (Akuoli et al., 2024; Gariba et al., 2021; Gindaba et al., 2024)

Lippia javanica is an aromatic shrub commonly known as lemon bush and has traditionally been used in Zimbabwe and other parts of southern Africa for pest control. Studies have shown that the essential oils of *L. javanica* exhibit insecticidal activity against pests supporting its potential as a botanical pesticide based on traditional knowledge (Kamanula et al., 2017; Maroyi, 2017). *Combretum imberbe* (leadwood) is a bushwillow tree native to southern Africa that has ethnobotanical importance and traditional applications in rural farming communities. Traditionally, resource poor farmers used its leaves and wood ash to protect grain from insect pests based on the hypothesis that its ash contains compounds that repel insect pests. Research indicates that the *C. imberbe* wood ash, effectively control storage pests such as *Oryzaephilus surinamensis* on cereals and pulses, thereby validating its traditional application as a natural, environmentally friendly grain protectant (Mfuma et al., 2025). Although these plants have been traditionally used by resource poor farmers to protect grain from insect pests, there is little scientific data on its efficacy on *P. truncatus* control in maize.

The purpose of this study was to investigate the efficacy of *Lippia javanica* leaf powder and *Combretum imberbe* wood ash in controlling *P. truncatus* in stored maize grain. The aim of the study was to develop a botanicals based sustainable, low cost and environmentally safe, synthetic pesticide alternative for the control of *P. truncatus in maize.* The first objective of the study was to ascertain the efficacy of *Lippia javanica* leaf powder and *Combretum imberbe* wood ash in promoting *P. truncatus* mortality and reducing *P. truncatus* population development. The second objective was to assess the level of maize grain damage by *P. truncatus* when the grain is treated with *Lippia javanica* leaf powder and *Combretum imberbe* wood ash before storage.

Materials and methods

Study location

The experiment was carried out at Panmure Plant Quarantine and Research Station (17° 16′ 37″ S, 31° 36′ 32″ E), Shamva district, in Zimbabwe. The site falls under natural agro-ecological region II, characterized with an average of 850 mm rainfall per annum and an annual temperatures range of 15–25 °C.

Experimental design

The study was carried out as two trials, where each trial consisted of six treatments replicated three times and arranged in a Complete Randomized Design (CRD). The first trial evaluated the efficacy of *Lippia javanica* leaf powder (Table 1) and the second trial evaluated the efficacy of *Combretum imberbe* wood ash (Table 2) against *P. truncatus* in stored maize. In each trial, treatments consisted of four dosage levels (2 g, 4 g, 6 g and 8 g per 200 g of maize grain), alongside an untreated control (negative control) and Actellic Gold Dust (positive control). The application rates (2, 4, 6, 8 g/200 g maize grain) were chosen according to the application range of previously conducted researches investigating botanical powders and ash material as storage insect protectant for grains under laboratory conditions (Golob et al., 1982; Meghwal & Bajpai, 2016). All treatments were applied to 200 g of disinfested maize grain, and both trials followed the same experimental layout, treatment structure, and management procedures to ensure consistency and comparability of results.

Insect rearing

Adult *P. truncatus* were collected from the Shamva communal area and used to establish a laboratory culture. The adult beetles were identified by their morphology, That is, reddish brown to dark brown in colour, approximately 4 mm in size, cylindrical shape, flattened and steep declivity and many small tubercles over the surface (Quellhorst et al., 2021). The identification was facilitated by the use of a magnifying glass. After collection, insects were sexed and male and female *P. truncatus* reared in separate containers. Sexing was done by checking the form of clypeal tubercles and confirmed by examining the genitalia for accurate identification (Gutierrez-Palomares et al., 2020). Arrangement and distribution of tubercle on the apical declivity differ between male and female beetles (Gutierrez-Palomares et al., 2020). To examine the genitalia, the abdomen of the beetles were squeezed to extrude the genitalia. The beetles that were accidentally damaged were excluded from the study. The insects were then reared in 1 L plastic containers (two separate containers, one for male and the other for female beetles) with perforated (6 × 1 mm holes) lids for aeration, each containing 500 g of clean, uninfected maize grains as a food source and oviposition substrate. The containers were kept under temperature conditions of 25–28 °C and 60–70% relative humidity for two weeks prior to experimentation. This rearing procedure produced a uniform cohort of adult *P. truncatus* insects reared in a similar condition, suitable for subsequent bioassay for assessing mortality, reproduction, and grain damage.

Preparation of botanicals

Fresh leaves of *Lippia javanica* were collected from the surrounding bushes. The leaves were dried at room temperature in a well-ventilated room for a period of 2 weeks. The dried leaves were pulverized to

Table 1. Treatments compared in a study to ascertain the effect of different dosage levels of *Lippia javanica* leaf powder on *Prostephanus truncatus*, a post-harvest maize pest.

Treatment	Description
1	Negative control, Untreated maize grain
2	*Lippia javanica* leaf powder at a rate of 2 g/200 g maize grain
3	*Lippia javanica* leaf powder at a rate of 4 g/200 g maize grain
4	*Lippia javanica* leaf powder at a rate of 6 g/200 g maize grain
5	*Lippia javanica* leaf powder at a rate of 8 g/200 g maize grain
6	Positive control, 200 g maize grain (treated with 4 g Actellic gold dust.

Table 2. Treatments compared in a study to ascertain the effect of different dosage levels of *Combretum imberbe* wood ash on *Prostephanus truncatus*, a post-harvest maize pest.

Treatment	Description
1	Negative control, Untreated maize grain
2	*Combretum imberbe* wood ash at a rate of 2 g/200 g maize grain
3	*Combretum imberbe* wood ash at a rate of 4 g/200 g maize grain
4	*Combretum imberbe* wood ash at a rate of 6 g/200 g maize grain
5	*Combretum imberbe* wood ash at a rate of 8 g/200 g maize grain
6	Positive control, 200 g maize grain (treated with 4 g Actellic gold dust.

a powder with a pestle in a mortar. The powder was sieved using a 0.2 mm mesh sieve and packed in air-tight closed glass container and stored in a refrigerator at before use. The *C. imberbe* wood was prepared by burning dry *C. imberbe* to ash using fire. The ash was then collected and sieved to obtain a fine powder. The fine powder ash was also packed in air-tight closed glass containers and stored at in a refrigerator before use.

Preparation of maize grain and infestation with Prostephanus truncatus

Twenty kilograms of newly harvested maize grain, variety SC513, was obtained from a local farmer. The maize was winnowed, and damaged grains were removed. The moisture content of the maize grain was adjusted to approximately 12–13% prior to experimentation, as recommended for safe storage conditions. Selected grains were disinfested by keeping them in a deep freezer set at −5 °C for 72 h. All life stages of insects, including egg and larvae stages, are sensitive to low temperature. The disinfested maize grains were conditioned to the laboratory environment by keeping them under the laboratory condition for 72 h before weighing then into groups of 200 g each for use in the trials. Each group of 200 g seeds was placed in transparent 250 g plastic bottle jar with a perforated lid (4 × 1 mm holes). The jars and their lids were disinfected by immersing them in a 1% sodium hypochlorite solution before use. *Lippia javanica* leaf powder, *C. imberbe* wood ash and Actellic Gold dust, were added according to the respective treatment dosage levels and thorough mixing of grain and treatment powders done to ensure uniform distribution of the treatment powders over the grain surface. The mixture was allowed to settle for 3 h before adult *P. truncatus* were introduced. Ten starved adult *P. truncatus* of different sexes (5 males and 5 females that had no opportunity to mate after collection) were introduced into each bottle. The *P. truncatus* were starved for 24 h before being introduced to the treatments. Only newly emerged adult insects (1–7 days old) were used to ensure uniform physiological status. The insects were introduced by placing them at the centre of the plastic bottle jars and the bottles were tightly closed and stored on a shelf at 25–28 °C temperature and 60–70% relative humidity in the laboratory for 1 week. Observations on the mortality and damage caused by P. *truncatus* was carried out after 7, 14 and 21 days of incubation. Only newly emerged adult insects (1–7 days old) were used to ensure uniform physiological status. The two trials were conducted under similar laboratory conditions but at separate times to avoid cross-contamination. After 21 days, adults were removed from the grain in the experimental jars and the grain was kept for F_1 progeny assessment.

Data collection

The efficacy of the treatments in the control of *P. truncatus* was assessed by determining insect mortality, reduction in insect reproduction, maintenance of grain weigh, and reduction of grain damage. To determine insect mortality and grain damage, the number of dead adult beetles and damaged grains were recorded 7, 14 and 21 days after infestation. At 7 and 14 days after infestation, live adults beetles were placed back in the plastic bottles for further incubation and the dead adults were discarded after counting. Insects were certified dead when their legs were motionless when the insects were teased with a small smooth brush. Mortality was calculated using the following equation:

$$Percentage\,mortality = \frac{Number\,of\,dead\,insects}{Total\,number\,of\,incubated\,insects} \times 100$$

To account for insects that could have died from effects other than the effect of the botanical pesticides, data on percentage adult insect mortality was corrected according to the method of Stathers et al. (2020) using the following formula;

$$Corrected\,mortality\,(\%) = \frac{\%Observed\,mortality - \%Control\,mortality}{100 - \%Conrol\,mortality}$$

Where control means the untreated control.

Grain damage was determined by counting damaged grain from a random sample of 100 seeds after 7, 14 and 21 days of incubation. Grains were deemed damaged when *P. truncatus* characteristic holes were observed. The percentage of insect damaged grains was computed using the method of Stathers et al. (2020) according to the following formula;

$$Percent\ grain\ damage = \frac{Number\ of\ damaged\ grain}{Total\ number\ of\ grain} \times 100$$

Percentage loss in grain weight due to *P. truncatus* damage during the incubation period was determined after 21 days of incubation. The count and weigh methods were used to count and weigh damaged and undamaged grains. The percentage weight loss was computed using the method by Kalsa et al. (2019), according to the following formula;

$$\text{Weight loss } (\%) = \frac{(Wu \times Nd) - (Wu - Nu)}{Wu \times (Nd + Nu)} \times 100$$

where *Wu* = weight of the undamaged grain; *Nu* = numbers of undamaged grain, *Wd* = weight of the damaged grain, and *Nd* = numbers of damaged grain.

After 21 days from infestation, all beetles, dead and alive, were discarded and the treatment grains were further incubated for 55 days. During this period, F_1 adult progeny *P. truncatus* beetles were counted once per week during the last four weeks. Evans (1985) reported that most F_1 offspring emerge during this time period. The effect of treatments in reducing reproduction of *P. truncatus* was determined as percent reduction according to Cortese et al. (2022) using the following formula,

$$Percent\ reduction = \frac{Total\ F1\ progeny\ in\ control - Total\ F1\ progeny\ in\ treatment}{Total\ F1\ progeny\ in\ control} \times 100$$

Where control means the untreated (negative) control.

Statistical data analysis

Data were analyzed by ANOVA using GenStat 16th Edition. The percent data (mortality, grain damage and reproductive inhibition) were arcsine square-root transformed prior to analysis in order to homogenize variance. Assumptions of normality and homogeneity of variance were tested using Shapiro–Wilk and Levene's test, respectively. Where significant effects of treatment were found ($p < 0.05$) Fisher's protected LSD was used for mean separation. Mortality and grain damage data collected over time were analyzed for each time point (7, 14 and 21 days). Graphs were constructed with Microsoft Excel 2013 and standard error bars are included on each graph.

Results

Mortality of P. truncatus in maize grains treated with L. javanica after 7, 14, and 21 days

The effect of different dosages of *L. javanica* leaf powder treatment on mortality of *P. truncatus* after 7, 14 and 21 days of incubation is shown in Figure 1. Significant treatment effects ($p < 0.05$) on the adult mortality rates at each time observation day were detected. Additionally mortality rate increased as the concentration of L. *javanica* leaf powder increases showing dose - related effects on mortality of pest at any given time of observation. No mortality was observed in the untreated control whereas all botanical applications applied resulted in statistically higher mortality rates across all the observation periods. Highest mortality rates observed amongst the botanicals was at 8 g (90%) and was comparable with that in the positive control (100%) (Actellic Gold Dust).

Grain damage caused by P. truncatus in maize treated with L. javanica leaf powder after 7, 14, and 21 days

The effect of different dosages of *L. javanica* leaf powder *P. truncatus* control treatment in maize grain damage after 7, 14 and 21 days of incubation is shown in Figure 2. Significant treatment differences ($p < 0.05$) in grain damage were observed across all the assessment periods. Grain damage increased with storage duration in all treatments although treated grains consistently recorded lower levels of damage than the untreated control. At 7 days after treatment, the untreated control recorded the highest percentage grain damage (94%), while all treated grains showed significantly lower damage levels. Grain protection increased with increasing dosage levels of *L. javanica* leaf powder. The 2 g treatment provided limited protection against grain damage, whereas the 6 g and 8 g treatments significantly reduced insect damage. The 8 g treatment consistently recorded the lowest grain damage among the botanical treatments and was statistically comparable to Actellic Gold Dust across all the assessment periods. After 21 days of incubation, severe grain damage was observed in the untreated control, while higher dosage treatments maintained comparatively low damage levels.

Weight loss in maize grains caused by P. truncatus after treatment with L. javanica after 21 days

The effect of different doses of *L. javanica* leaf powder treatment for the control of *P. truncatus* on grain weight loss after 21 days of incubation is shown in Figure 3. Significant treatment differences ($p < 0.05$) in grain weight loss due to *P. truncatus* damage were observed. The lowest weight losses occurred in maize treated with 8 g *L. javanica* (4%) and the synthetic insecticide Actellic Gold Dust (2%), with no

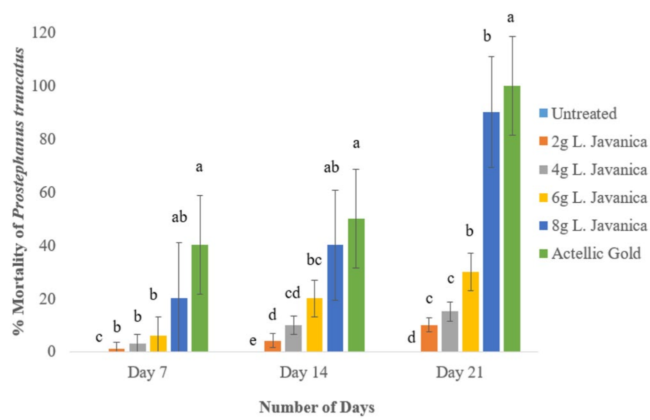

Figure 1. Mortality of *P. truncatus* in maize grains treated with *L. javanica* after 7, 14, and 21 days. Bars represent mean ± SE, means followed by different letters differ significantly ($p < 0.05$).

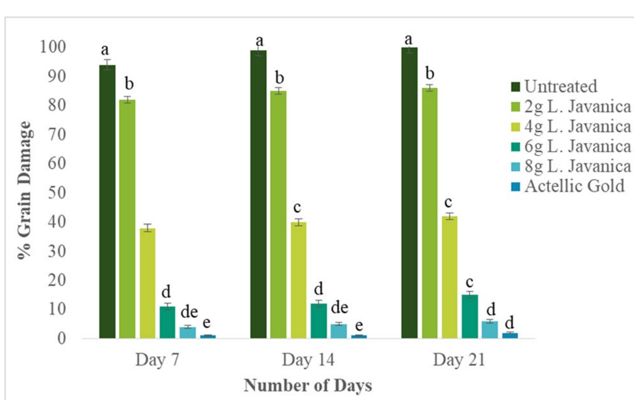

Figure 2. Grain damage caused by *P. truncatus* in maize treated with *L. javanica* leaf powder after 7, 14, and 21 days. Bars represent mean ± SE, means followed by different letters differ significantly ($p < 0.05$).

significant difference between the two. Untreated grain recorded the highest weight loss, followed by maize treated with 2g, 4g, and 6g of *L. javanica* leaf powder, respectively.

Prostephanus truncatus reproduction inhibition by Lippia javanica leaf powder after 21 days of incubation

The effect of treating maize grain with different dosages of *L. javanica* on reproduction of *P. truncatus* after 21 days of incubation is shown in Figure 4**.** Application of *L. javanica* leaf powder significantly ($p < 0.05$) reduced the emergence of F_1 adult *P. truncatus* progeny. Compared to untreated maize, F_1 adult *P. truncatus* progeny emergence was reduced by 5–85% from *L. javanica* dosage of 2g to 8g treatments, with higher dosages causing greater reductions. No adult insects emerged from maize treated with the synthetic insecticide (Actellic Gold Dust).

Mortality of P. truncatus in maize grains treated with combretum imberbe 7, 14, and 21 days

The effect of treating maize grain with different dosages of *Combretum imberbe* wood ash on *Prostephanus truncatus* after 7, 14 and 21 days of incubation is shown in Figure 5. Significant treatment differences ($p < 0.05$) in *P. truncatus* mortality were observed. Mortality increased with increasing rates of *C. imberbe* wood ash application. The highest mortality was recorded in maize treated with 8g of wood ash, which was not significantly different from that obtained with the synthetic pesticide Actellic Gold Dust at 7, 14 and 21 days of incubation respectively. The untreated control recorded the lowest mortality compared to the lowest dosage of *C. imberbe* wood ash. Increasing the dosage of *C. imberbe* wood ash to 4g, 6g and 8g gradually increased *C. imberbe* mortality, indicating a clear dose-dependent response. Notwithstanding the high mortality achieved at high dosages (6 and 8g/200g maize grain), treatment with *C. imberbe* wood ash had significantly lower mortality compared to Actellic Gold Dust, the positive control.

Grain damage caused by P. truncatus in maize treated with Combretum imberbe wood ash after 7, 14, and 21 days

The effects of treating maize grain with different dosages of *Combretum imberbe* Wood Ash to control *Prostephanus truncatus* on grain damage after 7, 14 and 21 days of incubation is shown in Figure 6. The mean percent grain damage was significantly lower ($p < 0.05$) in maize treated with *C. imberbe* wood ash compared to the untreated control. The 8g treatment caused the least damage among the botanical applications and the percent grain damage increase with decrease in *C. imberbe* wood ash dosage levels, demonstrating a clear dose-dependent effect. Actellic Gold Dust recorded the lowest overall damage, outperforming all other treatments.

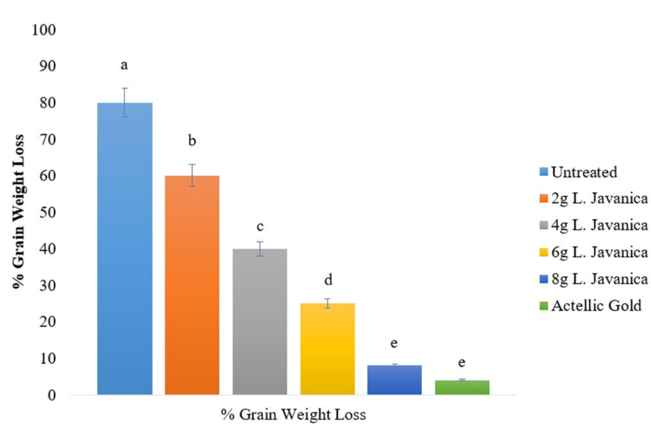

Figure 3. Weight loss in maize grains caused by *P. truncatus* after treatment with *L. javanica* 21 days. Bars represent mean ± SE, means followed by different letters differ significantly ($p < 0.05$).

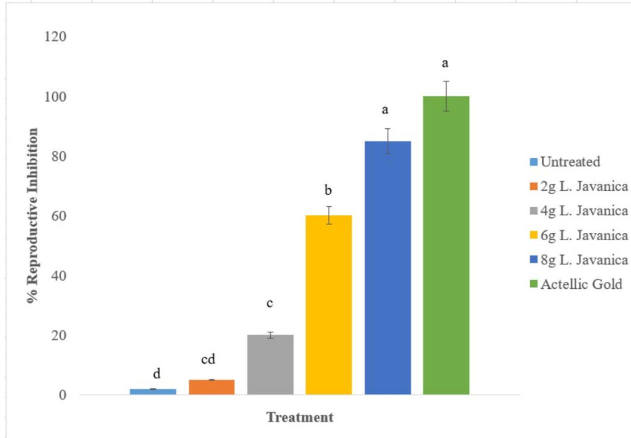

Figure 4. *Prostephanus truncatus* reproduction inhibition by *Lippia javanica* leaf powder after 21 days of incubation. Bars represent mean ± SE, means followed by different letters differ significantly ($p < 0.05$).

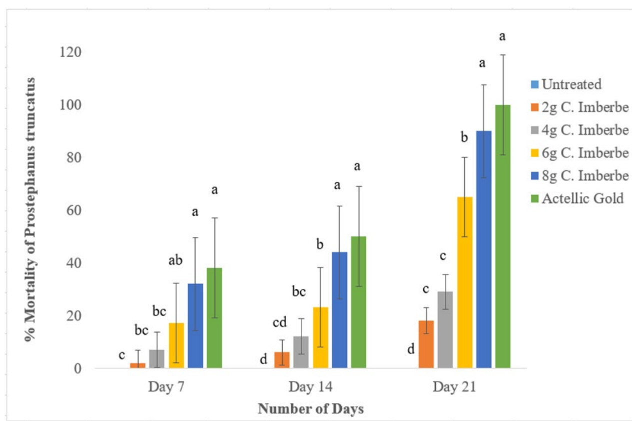

Figure 5. Mortality of *P. truncatus* in maize grains treated with *Combretum imberbe* 7, 14, and 21 days. Bars represent mean ± SE, means followed by different letters differ significantly ($p < 0.05$).

Weight loss in maize grains caused by P. truncatus after treatment with C. imberbe

The effects of treating maize grain with different levels of *C. imberbe* wood ash to control *P. truncatus* on grain weight loss after 21 days of incubation is shown in Figure 7. Significant treatment differences ($p < 0.05$) in grain weight loss were observed. The untreated control recorded the highest grain weight loss (82%), indicating severe damage by *P. truncatus*. The lowest weight loss occurred in maize treated with Actellic Gold Dust (3%), followed by the 8 g *C. imberbe* wood ash treatment (8%). There was no significant difference in grain weight loss among the 6 g, 8 g wood ash treatment and the positive control over the 21 day period.

Prostephanus truncatus reproduction inhibition by Combretum imberbe wood ash after 21 days of incubation

The effects of treating maize grain with *Combretum imberbe* wood ash on reproduction of *Prostephanus truncatus* after 21 days of incubation is shown in Figure 8. Application of *C. imberbe* wood ash significantly ($p < 0.05$) reduced the reproduction rates of *P. truncatus* compared to the untreated control. High adult F_1 progeny emergence was observed in the control and the 2 g treatment, indicating minimal suppression of population growth at low doses. Reproduction declined with increasing application rates, with higher doses markedly reducing or preventing F_1 progeny emergence. Actellic Gold Dust almost completely suppressed reproduction, while the 8 g *C. imberbe* treatment reduced progeny reproduction to below 20%.

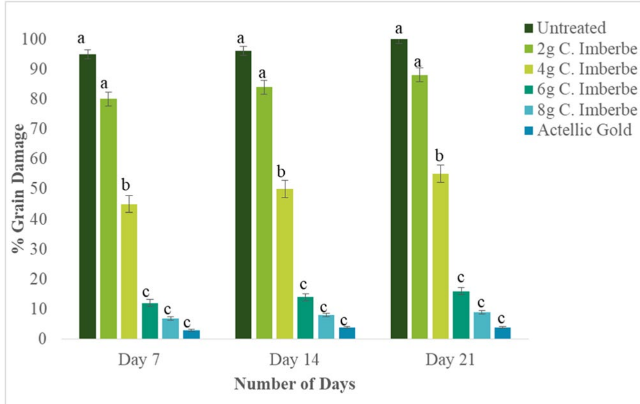

Figure 6. Grain damage caused by *P. truncatus* in maize treated with *Combretum imberbe* wood ash after 7, 14, and 21 days. Bars represent mean ± SE, means followed by different letters differ significantly ($p < 0.05$).

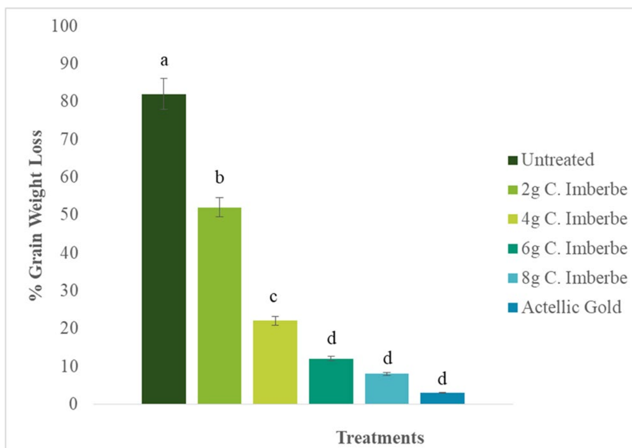

Figure 7. Weight loss in maize grains caused by *P. truncatus* after treatment with *C. imberbe*. Bars represent mean ± SE, means followed by different letters differ significantly ($p < 0.05$).

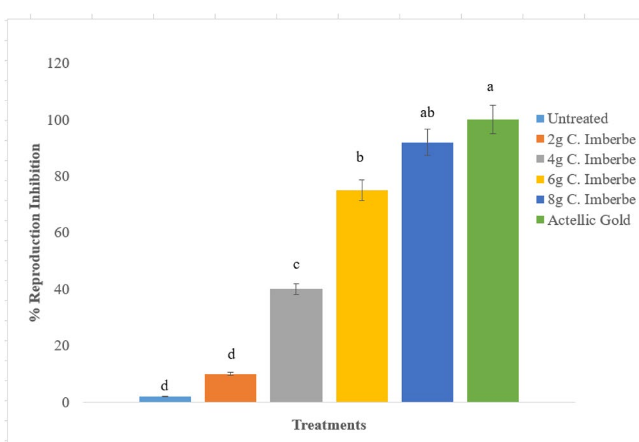

Figure 8. *Prostephanus truncatus* reproduction inhibition by *Combretum imberbe* wood ash after 21 days of incubation. Bars represent mean ± SE, means followed by different letters differ significantly ($p < 0.05$).

Discussion

The results demonstrate that *Lippia javanica* leaf powder and *Combretum imberbe* wood ash are promising botanical pesticides for managing *Prostephanus truncatus* in stored maize. Both botanicals significantly increased adult mortality, decreased the damage of grain, weight loss of grain and F_1 progeny emergence compared with the untreated control. The higher the dosage levels, the higher the treatment effects were, showing dose-dependent responses. Similar observations had been found by some other studies that botanicals powders and ashes reduced the population of storage insect pests greatly by their toxic, repellent, anti-feeding and desiccation effects (Gariba et al., 2021; Ileke et al., 2016; Rajashekar et al., 2025).

The higher mortality obtained when the maize was treated with *Lippia javanica* leaf powder may be due to the existence of many chemical active ingredients such as terpenoids, alkaloids, flavonoids, essential oils that exhibit strong insecticidal and repellency effect (Kamanula et al., 2017; Maroyi, 2017). These may affect respiration, movement and feeding habits and ovipositional behavior of the pest and hence mortality and decrease in their reproduction. Very fine powders can also cause clogging of spiracles and desiccation to insects. Similarly, in the case of *Combretum imberbe* wood ash, the effect was mainly due to its physical mode of action. Dust and fine particles in the ash cut the cuticle of insect, caused desiccation and reduced the palatability and induced an unsuitable environment for insects feeding and reproduction (Fening et al. 2015; Wini Goudoungou et al., 2018).

Both botanicals were able to suppress the population of *P. truncatus* to varying degrees and their differences may be due to their mechanism of action. *Lippia javanica* exhibited a higher effect on reproduction suppression especially at lower dose compared to *C. imberbe* wood ash. It is probably due to volatile compounds present in it. Essential oils and other chemical substances in *Lippia javanica* leaf powder could directly influence the mating behavior, ovulation process, oviposition behavior and fertilization rate and also the development of larvae and emergence of adults from egg, which could have attributed to reproductive suppression of the pest (Kamanula et al., 2017). The *C. imberbe* wood ash's mode of action is mainly related to physical effect causing desiccation (Wini Goudoungou et al., 2018). However, the effects are profound and acceptable at higher doses.

Grain damage and grain weight loss closely followed trends similar to those observed for insect mortality and reproductive suppression. The treatments of grain using both botanicals had less damage to grain and less weight loss of grain compared to that of untreated control in high dose treatments. Less damage to grain could have resulted from lower number of feeding or fewer numbers of insects on the grain. This has also been observed by some other researchers when using powders of plants and ash-based formulations to protect grain against storage insect pests such as *Sitophilus zeamais* and *Prostephanus truncatus* (Akuoli et al., 2024; Gariba et al., 2021). Significant reduction in grain damage is important, as substantial damage by storage insect pests not only reduce the amount of grain available but also its quality.

The effect on the emergence of F_1 generation in this study showed that the botanicals not only act on the survival of adults but also have significant influence on the reproductive behavior and reproduction of pests. The F_1 progeny emerge was greatly reduced and this may be related to the effects on oviposition, embryonation, development of larvae, and survival from egg to adult stage. Possibly botanical treatments alter the microenvironment for egg lying and also movement behavior on grain surface (Cortese et al., 2022; Mehta & Kumar, 2020). Reproduction control is important because even small infestation of *P. truncatus* in stores can reach economic threshold level quickly.

Actellic Gold Dust gave the best mortality and lower damages to the grain and progeny emergence. The effective ingredients in the synthetic pesticide; pirimiphos-methyl and permethrin act rapidly to kill the insect by neurological effects, leading to quick knockdown effects (Cathrine et al., 2022). However, higher dosages of the botanicals even at 8 g application for both *L. javanica* leaf powder and *C. imberbe* wood ash were not statistically different with Actellic Gold Dust in some parameter. This implies that such botanical could be alternatives of the synthetics, as synthetic pesticides are mostly expensive and have some other disadvantages such as the residue of the chemical on the food and damage on non-target organisms (Moreira & Da Silva, 2023; Pu & Chung, 2024).

Therefore, using leaf powder of *L. javanica* and wood ash of *C. imberbe* in stored maize could be a cheaper, environment friendly and alternative protection strategy to synthetic pesticide. They may provide alternative for poor and small holder farmers who cannot afford synthetic pesticide. Using plant-based pesticides may also reduce the reliance on commercial imported synthetic pesticides and lead to sustainable post-harvest management system and food security program.

However, the feasibility of applying 8 g of these botanicals per 200 g of maize grain (about 4% w/w) need to be studied further. Even though it is manageable for small holder farmers using locally available materials but maybe it may be laborious when large quantities of grain stored. In addition, these relatively large volumes of ash and powder could result in difficulties during cleaning prior to marketing or further processing. Future studies can be done to assess the economic feasibility, farmer acceptability, and effects of these botanical treatments on grain quality under practical storage conditions.

The experiments were performed under laboratory conditions and the amount of grain used was comparatively small. However, actual storage condition may differ from those used in the lab experiment, in terms of fluctuation in temperature, humidity, duration of storage and volume of the grain. Thus further research is required to evaluate the effectiveness of the treatments under farmer storage conditions. Long-term studies on residual effect of the botanical treatments in grain have to be undertaken. The combination of the botanicals and the hermetic storage systems need also to be investigated.

Acknowledgements

The authors sincerely thank the Panmure Plant Quarantine and Research Station for providing the experimental facilities that supported this study. We are especially grateful to the staff for their practical assistance during insect rearing, sample preparation, and data collection. Their cooperation and support were invaluable to the successful completion of the laboratory work.

Author contributions

CRediT: **Lorraine Yeukai Chihumbiri**: Formal analysis, Investigation, Methodology; **Zivanayi Musabayana**: Conceptualization, Formal analysis, Methodology, Software, Supervision; **Mandhlenkosi Zhou**: Software, Visualization, Writing – original draft, Writing – review & editing; **Ndabanye Mathema**: Validation, Writing – original draft, Writing – review & editing; **Lenon Tembo**: Writing – original draft, Writing – review & editing; **Pesanai Zanamwe**: Supervision, Writing – original draft, Writing – review & editing.

Ethical considerations

This study followed all ethical standards for research, without direct contact with human beings or animals.

Disclosure statement

The authors declared no conflict of interests.

Funding

No funding was received for this research.

ORCID

Lorraine Yeukai Chihumbiri http://orcid.org/0009-0005-8523-3536
Zivanayi Musabayana http://orcid.org/0009-0003-3701-2101
Mandhlenkosi Zhou http://orcid.org/0009-0004-7155-6601
Ndabanye Mathema http://orcid.org/0000-0002-5722-2160
Lenon Tembo http://orcid.org/0009-0008-4363-4894
Pesanai Zanamwe http://orcid.org/0000-0001-6011-2416

Data availability statement

The data supporting the findings of this study are available upon request from the corresponding author. The data were not publicly available because of privacy or ethical restrictions.

References

Adimas, Z. T., Adimas, M. A., & Abera, B. D. (2024). Plant-based bioactive compounds for grain storage: A comprehensive review. *Cogent Food & Agriculture*, *10*(1), 2316152. https://doi.org/10.1080/23311932.2024.2316152

Affognon, H., Mutungi, C., Sanginga, P., & Borgemeister, C. (2015). Unpacking postharvest losses in Sub-Saharan Africa: A meta-analysis. *World Development*, *66*, 49–68. https://doi.org/10.1016/j.worlddev.2014.08.002

Akuoli, A., Kugbe, J. X., Adu-Acheampong, S., & Kyerematen, R. (2024). Two plant extracts protect stored maize against infestation of *Sitophilus zeamais* in Northern Ghana. *Journal of Natural Pesticide Research*, *10*, 100102. https://doi.org/10.1016/j.napere.2024.100102

Anagiotakis, A. P., Baliota, G. V., Rumbos, C. I., & Athanassiou, C. G. (2023). Efficacy of contact insecticides for the control of the larger grain borer, *Prostephanus truncatus* (Horn), on stored maize. *Agriculture*, *13*(8), 1502. https://doi.org/10.3390/agriculture13081502

Arthur, F. H., Bean, S. R., Smolensky, D., Gerken, A. R., Siliveru, K., Scully, E. D., & Baker, N. (2020). Development of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) on sorghum milling fractions. *Journal of Stored Products Research*, *87*, 101606. https://doi.org/10.1016/j.jspr.2020.101606

Cathrine, S., Lovejoy, T., & Rumbidzai, C. R. (2022). Effectiveness of Tick Berry (*Lantana camara*) in controlling larger grain borer (*Prostephanus truncatus*) in stored maize. *Asian Food Science Journal*, *21*(3), 10–18. https://doi.org/10.9734/afsj/2022/v21i330413

Cortese, D., Mareco Da Silva, M. M., de Oliveira, G. S., Mussury, R. M., & Fernandes, M. G. (2022). Repellency and reduction of offspring emergence potential of some botanical extracts against *Sitophilus zeamais* (Coleoptera: Curculionidae) in stored maize. *Insects*, *13*(9), 842. https://doi.org/10.3390/insects13090842

Edoh Ognakossan, K., Tounou, A. K., Lamboni, Y., & Hell, K. (2012). Post-harvest insect infestation in maize grain stored in woven polypropylene and in hermetic bags. *International Journal of Tropical Insect Science*, *33*(01), 71–81. https://doi.org/10.1017/S1742758412000458

Ekpa, O., Palacios-Rojas, N., Kruseman, G., Fogliano, V., & Linnemann, A. R. (2019). Sub-Saharan African Maize-based foods – processing practices, challenges and opportunities. *Food Reviews International*, *35*(7), 609–639. https://doi.org/10.1080/87559129.2019.1588290

Fening, K. O., Brentu, F. C., & Alidu, A. I. (2015). Using ash from wood or rice husk to control maize weevils. *PlantwisePlus Knowledge Bank*. *CABI*. https://doi.org/10.1079/pwkb.20157800396

Gariba, S. Y., Dzidzienyo, D. K., & Eziah, V. Y. (2021). Assessment of four plant extracts as maize seed protectants against *Sitophilus zeamais* and *Prostephanus truncatus* in Ghana. *Cogent Food & Agriculture*, *7*(1), 1918426. https://doi.org/10.1080/23311932.2021.1918426

Gindaba, A., Negeri, M., Abdisa, B., Nemo, R., & Kitila, C. (2024). Phytochemical screening and insecticidal activities of some medicinal plants against the maize weevil, *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae). *Scientific Reports*, *14*(1), 8678. https://doi.org/10.1038/s41598-024-59207-z

Golob, P., Mwambula, J., Mhango, V., & Ngulube, F. (1982). The use of locally available materials as protectants of maize grain against insect infestation during storage in Malawi. *Journal of Stored Products Research*, *18*(2), 67–74. https://doi.org/10.1016/0022-474X(82)90004-2

Gutierrez-Palomares, V. M., Gutierrez-Chacon, F., Lopez-Buenfil, J. A., & Chavarin-Palacio, C. (2020). Sexual Differentiation of the Large Grain Borer, *Prostephanus truncatus*1, by External Morphometry. *Southwestern Entomologist*, *45*(1), 123. https://doi.org/10.3958/059.045.0113

Ileke, K. D., Adesina, J. M., & Obajulaye, E. O. (2016). Synergetic effects of two botanical entomocides as pest-protectants in maize grains. *Journal of Biological Research – Bollettino Della Società Italiana di Biologia Sperimentale*, *89*(2), 101702. https://doi.org/10.4081/jbr.2016.5917

Ileke, K. D., Idoko, J. E., Ojo, D. O., & Adesina, B. C. (2020). Evaluation of botanical powders and extracts from Nigerian plants as protectants of maize grains against maize weevil, *Sitophilus zeamais* (Motschulsky) [Coleoptera: Curculionidae]. *Biocatalysis & Agricultural Biotechnology*, *27*, 101702. https://doi.org/10.1016/j.bcab.2020.101702

Kalsa, K. K., Subramanyam, B., Demissie, G., Mahroof, R., Worku, A., & Gabbiye, N. (2019). Evaluation of post-harvest preservation strategies for stored wheat seed in Ethiopia. *Journal of Stored Products Research*, *81*, 53–61. https://doi.org/10.1016/j.jspr.2019.01.001

Kamanula, J. F., Belmain, S. R., Hall, D. R., Farman, D. I., Goyder, D. J., Mvumi, B. M., Masumbu, F. F., & Stevenson, P. C. (2017). Chemical variation and insecticidal activity of *Lippia javanica* (Burm. f.) Spreng essential oil against *Sitophilus zeamais* Motschulsky. *Industrial Crops & Products*, *110*, 75–82. https://doi.org/10.1016/j.indcrop.2017.06.036

Liang, J., Xiao, F., Ojo, J., Chao, W. H., Ahmad, B., Alam, A., Abbas, S., Abdelhafez, M. M., Rahman, N., Khan, K. A., Ghramh, H. A., Ali, J., & Chen, R. (2025). Insect resistance to insecticides: Causes, mechanisms, and exploring potential solutions. *Archives of Insect Biochemistry & Physiology*, *118*(2), e70045. https://doi.org/10.1002/arch.70045

Mapara, J., & Mazuru, M. (2015). Indigenous knowledge systems and their implications for sustainable development in Zimbabwe. *Journal of Pan African Studies*, *8*(9), 139–155.

Maroyi, A. (2017). *Lippia javanica* (Burm.f.) Spreng.: Traditional and commercial uses and phytochemical and pharmacological significance in the African and Indian Subcontinent. *Evidence-Based Complementary & Alternative Medicine: eCAM*, *2017*(1), 6746071. https://doi.org/10.1155/2017/6746071

Meghwal, H. P., & Bajpai, N. K. (2016). Relative efficacy of plant products as grain protectant against Sitophilus oryzae in stored maize grains. *Annals of Arid Zone*, *51*(1), 47–51. https://doi.org/10.56093/aaz.v51i1.63469

Mehta, V., & Kumar, S. (2020). Influence of different plant powders as grain protectants on Sitophilus oryzae (L.) (Coleoptera: Curculionidae) in stored wheat. *Journal of Food Protection*, *83*(12), 2167–2172. https://doi.org/10.4315/jfp-20-153

Mfuma, M. K., Legwaila, M. M., & Makate, N. (2025). Evaluation of *Combretum imberbe* wood ash for control of *Oryzaephilus surinamensis* (Linn) on stored food commodities in Botswana. *Journal of Entomology & Zoology Studies*, *13*(6), 184–190. https://doi.org/10.22271/j.ento.2025.v13.i6c.9647

Minozzo, M., Steffens, J., Backes, G. T., Paroul, N., & Cansian, R. L. (2021). Biological potential and microencapsulation of *Cinnamomum cassia* essential oil as an alternative for pest control in stored maize. *Research, Society & Development*, *10*(14), e530101422334. https://doi.org/10.33448/rsd-v10i14.22334

Moreira, A., & Da Silva, M. V. (2023). Pesticide application as a risk factor/behaviour for workers' health: A systematic review. *Environments*, *10*(9), 160. https://doi.org/10.3390/environments10090160

Mutambuki, K., Affognon, H., Likhayo, P., & Baributsa, D. (2019). Evaluation of Purdue improved crop storage triple layer hermetic storage bag against *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) and *Sitophilus zeamais* (Motsch.) (Coleoptera: Curculionidae). *Insects*, *10*(7), 204. https://doi.org/10.3390/insects10070204

Ngom, D., Thiaw, C., & Sembène, M. (2020). Interspecific competition and grain-hosts selection of Maize Weevil, *Sitophilus zeamais* (Motsch.) (Coleoptera; Dryophtoridae) and larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera; Bostrichidae). *Advances in Entomology*, *8*, 34–45. https://doi.org/10.4236/ae.2020.81003

Nowakowska-Świrta, E., Wiszniewska, M., & Walusiak-Skorupa, J. (2019). Allergen-specific IgE to recombinant latex allergens in occupational allergy diagnostics. *Journal of Occupational Health*, *61*(5), 378–386. https://doi.org/10.1002/1348-9585.12064

Pu, J., & Chung, H. (2024). New and emerging mechanisms of insecticide resistance. *Current Opinion in Insect Science*, *63*, 101184. https://doi.org/10.1016/j.cois.2024.101184

Quellhorst, H., Athanassiou, C. G., Zhu, K. Y., & Morrison, W. R. (2021). The biology, ecology and management of the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). *Journal of Stored Products Research*, *94*, 101860. https://doi.org/10.1016/j.jspr.2021.101860

Rajashekar, Y., Devaraja, A., Thirumalesh, B. V., & Vivek Babu, C. S. (2025). Botanical insecticides for stored grain protection: Emerging challenges and future prospects. *Food Bioscience*, *71*, 107337. https://doi.org/10.1016/j.fbio.2025.107337

Stathers, T. E., Arnold, S. E. J., Rumney, C. J., & Hopson, C. (2020). Measuring the nutritional cost of insect infestation of stored maize and cowpea. *Food Security*, *12*(2), 285–308. https://doi.org/10.1007/s12571-019-00997-w

Suleiman, R., Bern, C. J., Brumm, T. J., & Rosentrater, K. A. (2018). Impact of moisture content and maize weevils on maize quality during hermetic and non-hermetic storage. *Journal of Stored Products Research*, *78*, 1–10. https://doi.org/10.1016/j.jspr.2018.05.007

Wini Goudoungou, J., Nchiwan Nukenine, E., Suh, C., Gangué, T., & Ndjonka, D. (2018). Effectiveness of binary combinations of *Plectranthus glandulosus* leaf powder and *Hymenocardia acida* wood ash against *Sitophilus zeamais* (Coleoptera: Curculionidae). *Agriculture & Food Security*, *7*(1). https://doi.org/10.1186/s40066-018-0179-z